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APPLYING THE KALMAN FILTER TO THE EMITTER LOCATION PROBLEM USING AIRBORNE ANGLE-OF-ARRIVAL INFORMATION

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THESIS

APPLYING THE KALMAN FILTER TO THE EMITTER LOCATION PROBLEM USING AIRBORNE ANGLE-OF-ARRIVAL INFORMATION

by

Edward Harlan Mills

Thesis Advisor: H. A. Titus

March 1973

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Applying the Kalman Filter to the Emitter Location Problem Using Airborne Angle-of-Arrival Information

by

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Captain, United States Marine Corps
B.S., United States Naval Academy, 1967

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

A scheme to locate emitter positions using post flight processing of discrete airborne emitter bearing angles-of-arrival information and recorded aircraft position coordinates by Kalman filter techniques is developed. The signal intercept system was assumed to be operating in a multi-emitter environment and all data was sampled at discrete but time varying intervals. The aircraft position data is filtered directly in latitude and longitude and emitter locations are computed in latitude and longitude using vector methods. An extended Kalman filtering scheme is developed to compute emitter coordinates directly in latitude and longitude coordinates.

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I. INTRODUCTION

With the ever increasing reliance of the military forces on electromagnetic systems for communication, reconnaissance, and weapons control, there is a correspondingly increasing requirement to detect and locate the position of the enemy emitters.

The complexity of this problem was shown by F. Pfendtner in [1]. When there are multiple emitters in reasonable proximity and several observations, called direction finding (DF) bearings, are made, the number of possible locations I, of these emitters is found by

$$I = m^2 n(n-1)/2$$

where m is the number of emitters and n is the number of observations.

If there were six emitters and ten observations of each emitter, there would be a possibility of 1,620 points of bearing line intersections, each a valid emitter position.

A scheme was developed in [1] to locate the most probable location of the emitter based on the mean of all points of intersection associated with a given target. This scheme did not provide the desired degree of accuracy. So, a scheme was developed to Kalman filter all of the DF bearing correlated with a given target, thus finding an optimal estimate of these observations. The first and last estimates

of the DF bearings to each target were used to determine emitter location by triangulation methods. This scheme provided solutions much closer to the desired accuracy.

Any solution is only as good as the data used to compute it, so, L. L. Coburn developed a data sort scheme in [2] which would compare all of the observations and correlate each data point with a specific target to avoid the possibility of basing the solution of an emitter position on observations not from that target. The sort was based on signal carrier frequency and pulse repetition frequency, PRF. The data sort utilized in [2] was only an initial sort in that any observations not passing a later comparison test were discarded and not saved for locating further emitter sites.

In this study an initial data sort based on signal carrier frequency and PRF is utilized, but all observations are eventually correlated to a target or are labeled as single line bearings.

Also for this report a routine was developed to determine optimal estimates of aircraft position coordinates by filtering and smoothing aircraft position observations.

An extended Kalman filter was developed to filter the estimate of the target position directly in latitude and longitude. This routine could be used to track moving targets, or to filter emitter positions based on data from several flights. Only signal parameters, the estimates of

aircraft position, observed DF bearing angles, time data, and the estimated target position would need to be stored from each flight for further processing.

II. PROBLEM DESCRIPTION

A. KALMAN FILTER THEORY

Sequential estimation is characterized by the serial recursive processing of observations taken in time sequence. The result of every processing cycle is the current best estimate of the vector being estimated. This estimate therefore embodies all observation data up to and including the current observation. As a new observation is made, the current estimate is updated to reflect this most recent data.

In such an estimation scheme the calculations are identical in nature from cycle to cycle so they are ideally suited for implementation on a digital computer.

The problem presented in this report is that of the post flight processing of digitized data, but the program utilized in this case could easily be adapted for a real-time processor for in-flight computing and real-time locating of emitter sites.

The Kalman filter [3] is a recursive filter of the type needed for this application. Since the data inputs are already in digital form, the discrete form of the Kalman Filter are utilized for processing on a digital computer.

From the probabilistic description of the random signal and noise we can determine the probability with which a particular sample of the signal and noise will occur and we can therefore estimate $x(k)$. This estimate will be denoted by $\hat{x}(k)$

The discrete system under consideration satisfies

$$x(k+1) = \phi(k)x(k) + w(k) \tag{1}$$

$$z(k) = h(k)x(k) + v(k) \tag{2}$$

where x is an n x 1 state vector, z is an m x 1 output vector, w is a zero-mean n x 1 vector of state excitation white noise, uncorrelated with the zero-mean-additive observation white noise vector v, ϕ is the state transition matrix and h is the observation matrix. The noise statistics are

$$E\left[v(k)\ v(j)^T\right] = R(k)\ \delta(k,j) \tag{3}$$

$$E\left[w(k)\ w(j)^T\right] = Q(k)\ \delta(k,j) \tag{4}$$

$$E\left[v(k)\ w(j)^T\right] = 0 \quad \text{for all } (k,j) \tag{5}$$

$$\delta(k,j) = \begin{cases} 0 & k \neq j \\ 1 & k = j \end{cases} \tag{6}$$

The Kalman filter recursion equations [4] are summarized below where $\hat{X}(k|j)$ denotes the estimate of the state X(k) based upon j measurement observations Z(1),Z(2),...,Z(j).

$$P(k|k-1) = \phi(k,k-1)P(k-1|k-1)\phi(k,k-1)^T + Q(k) \tag{7}$$

$$G(k) = P(k|k-1)H(k)\left[H(k)P(k|k-1)H(k)^T + R(k)\right]^{-1} \tag{8}$$

$$P(k|k) = P(k|k-1) - G(k)H(k)P(k|k-1) \tag{9}$$

$$\hat{X}(k|k) = \hat{X}(k|k-1) + G(k)\left[Z(k) - H(k)\hat{X}(k|k-1)\right] \tag{10}$$

$$\hat{X}(k|k-1) = \phi(k,k-1)\hat{X}(k-1|k-1) \tag{11}$$

where G(k) is the Kalman filter gain matrix and $P(k|j)$ is the error covariance matrix.

B. SYSTEM MODELS

The emitter position locating system modeled was divided into three distinct systems, (1) aircraft navigation system, (2) the DF bearings, and (3) the target location. The combined system consists of five linear Kalman filters, plus one linearized Kalman filter, called an extended Kalman filter, and two smoothing filters. Each of these models will be described briefly in this section with more detailed descriptions in Section III, "Computational Procedures."

All of the systems are modeled by a linear $1/s^2$ plant. The state transition matrix, ϕ, is

$$\phi(k+1,k) = \begin{bmatrix} 1 & T(k+1) \\ 0 & 1 \end{bmatrix} \qquad (12)$$

where T(k+1) = TIME T(k+1) - TIME T(k), TIME T being the time of observation.

To minimize the affects of the inherent uncertainty of the system model, the values of Q should be increased to a value which ensures that each observation is utilized. The effect of increasing the magnitude of Q is seen from (7) to be larger values of the error covariance matrix, P, which leads to an increase in the filter gain matrix G. This means that the filter is paying more attention to the actual measurement to compensate for errors in the plant model. Thus, the more nonlinear the system dynamics, the larger Q

should be. If the measurement errors are in question, R should be increased which, as can be seen from (8), will decrease G so the filter relies more on the total effect of all previous measurements, i.e. the previous estimate of the system states [5].

1. Aircraft Navigation System Model

The navigation system is modeled by a constant velocity plant for each direction of aircraft travel, east-west and north-south, with the system states for each plant being aircraft position and aircraft velocity. Only the aircraft position fixes were observable so the objective of this filter is to filter the noisy observed position coordinates to obtain optimal estimates of own aircraft location. These estimates are used in processing the DF bearings and target positions.

Since only aircraft position coordinates were observed, the observation matrix is H = [1 0]. This made W(k), V(k) and R(k) scalar variance terms and the bracketed terms in (8) and (10) become scalar as well.

Since W is a scalar, (4) becomes

$$\Gamma E\left[W\ W^T\right]\ \Gamma^T \Big| = \Gamma\ \Gamma^T\ E\left[W^2\right]. \tag{13}$$

Substituting the expression for Γ into (13) yields

$$Q(k) = E\left[W^2\right]\begin{bmatrix} \dfrac{T^4(k)}{4} & \dfrac{T^3(k)}{2} \\ \dfrac{T^3(k)}{2} & T^2(k) \end{bmatrix} \tag{14}$$

2. DF Bearing Model

The system states for the problem of angle filtering are DF bearing angle-of-arrival and bearing rate. In this program the system dynamics are also modeled by a constant velocity plant. The bearing rate is unobservable so the observation matrix is $H = [1 \quad 0]$ as in the navigation data filter equations.

This model does not accurately represent the actual system since the estimated angular rate error increases with time[1]. However by introducing a non zero Q matrix this error can be reduced. The effect of Q on the accuracy of this model can be seen in the results obtained by L. L. Coburn [2].

3. Target Position Coordinates Model

The states of the target location system are latitude, latitude rate, longitude, and longitude rate while the observations are the noisy DF bearings only. To compute the optimal estimate of the states, the system was modeled by two linear constant velocity systems, one each for latitude and longitude. A linearized transformation of the measurement equation was utilized to provide DF bearing information to the latitude and longitude filters in a form they could use to filter their states.

The models for the two linear systems are again $1/s^2$ plants with $H = [1 \quad 0]$.

The target location system model is shown in Fig. 1, and is discussed further in Section III, part F, "Extended Kalman Filter."

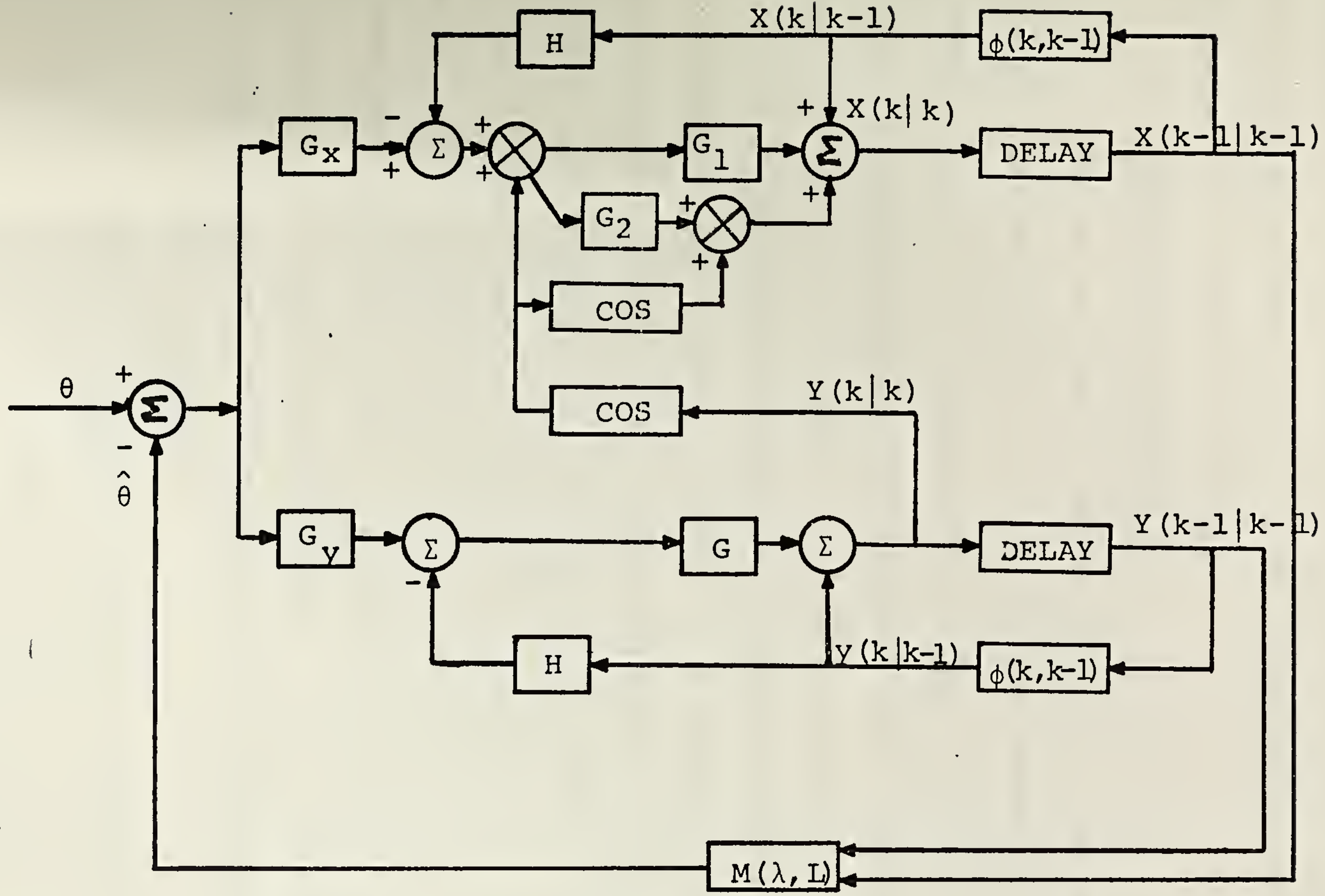

Figure 1. Extended Kalman Filter Block Diagram.

C. SMOOTHING

Two types of smoothing are utilized in this program, fixed point with the angle filter and fixed interval with the navigation data filter. The fixed point smoothing technique will be discussed first.

1. Fixed Point Smoothing

In the process of angle filtering, the estimate of the DF bearing, $\hat{\theta}(n|n)$, is a weighted "average" of all previous noisy DF bearings, $\theta(1),\theta(2),\ldots,\theta(n)$. However the actual position finding algorithm (POSIT) utilizes the estimate of the first DF bearing, $\hat{\theta}(1|n)$, as well as $\hat{\theta}(n|n)$. So, the first bearing should be somehow weighted by all successive cuts, $\theta(2),\ldots,\theta(n)$. The technique used to accomplish this filtering is called fixed point smoothing. The smoothing equations are similar to the Kalman filter equations in that they are recursive in nature and functions of similar statistical parameters. The difference is that the smoothing filters produce a previous estimate of the state subject to successive measurements. The fixed point smoothing equations used in this program are summarized below [6].

a. Gain Equation

$$\hat{X}(k|j) = \hat{X}(k|j-1) + W(j)H(j)^{T}R^{-1}(j)\Big[Z(j) - H(j)\phi(j,j-1)\hat{X}(j-1|j-1)\Big] \qquad (15)$$

where $j = k+1, k+2, \ldots,$ and the initial condition is $\hat{X}(k|k)$.

b. Gain Equation

$$W(j) = W(j-1)\phi\ (j,j-1)^T \left[I-S(j)P(j|j)\right] \quad (16)$$

where $W(k) = P(k|k)$ and $S(j) = H(j)^T R^{-1}(j)H(j)$

c. Covariance Equation

$$P(k|j) = P(k|j-1) - W(j) \left[S(j)P(j|j-1)S(j) + S(j)\right] W(j)^T \quad (17)$$

where the initial condition is $P(k|k)$. $P(j|j)$ and $P(j|j-1)$ are the error covariance matrices from the optimal filter.

2. Fixed Interval Smoothing

The second type of smoothing utilized is the fixed interval smoothing. In the navigation data filtering routine, the flight track is broken into legs with a new leg being initiated any time the aircraft flies for more than two minutes without recording a position fix. Each leg is then an interval and each interval is filtered and smoothed separately. The motivation for the fixed interval smoothing routine is similar to that for smoothing in the angle filtering routine, i.e. each estimate should be influenced by each successive measurement as well as by each previous one. The fixed interval smoothing equations utilized in the angle filter are [6]. Utilized in the angle filter are [6]:

a. Filter Equation

$$\hat{X}(k|n) = \hat{X}(k|k) + A(k)\left[\hat{X}(k+1|n) - \hat{X}(k+1|k)\right] \quad (18)$$

for $k = n-1, n-2, \ldots, 0$, where $X(n|n)$ is the boundary condition for $k = n-1$.

b. Gain Equation

$$A(k) = P(k|k)\phi\,(k+1,k)^T P^{-1}(k+1|k) \qquad (19)$$

c. Covariance Equation

$$P(k|n) = P(k|k) + A(k)\left[P(k+1|n) - P(k+1|k)\right] A(k)^T \qquad (20)$$

This filter has the advantage taht it incorporates the covariance terms, $P(k|k)$ and $P(k+1|k)$, as well as the estimates $X(k|k)$ and $X(k+1|k)$ from the Kalman filter equations, so the required number of computations is minimized. Since $k = n-1, n-2, \ldots, 0$, it is clear that this system of equations is recursive backwards in time so it does indeed produce a smoothed estimate of each navigational fix subject to all successive fixes on that leg.

D. INITIAL EMITTER POSITION FIXING

Each position on the earth can be considered to be the tip of a vector whose length is the radius of the earth.

In this problem the radius of the earth is assumed to be constant. Even though it is known that the constant radius assumption is an inaccurate one, using a constant value for the radius produces an error of less than two percent of the distance involved anywhere on the surface of the earth [7]. Also by using this assumption this method is equally valid over the entire globe without regard for the radius.

The position vector can be described either by its latitude and longitude or in x,y,z coordinates on a three

dimensional coordinate system with the center of the earth as the origin of the system, as in Fig. 2.

The latitude is the angle in a meridian plane measured from the equatorial plane to the radius vector of the aircraft. Longitude is the angle in the equatorial plane measured from the Greenwich meridian to the meridian of the aircraft. The latitude of a point on the earth is in the range 0 to 90 degrees in the northern hemisphere and from 0 to -90 degrees in the southern hemisphere. The longitude of a point on the earth is in the range 0 to 180 degrees in the eastern hemisphere and from 0 to -180 in the western hemisphere. In the 3-D right hand coordinate system the positive z axis passes through the geographic north pole, the positive x axis passes through the Greenwich meridian and lies in the equatorial plane and the positive y axis passes through 90 degrees east longitude and lies in the equatorial plane [8].

The relationship between the latitude and longitude coordinates (ϕ,θ) and the (x,y,z) coordinates is expressed by the formulae

$$x = \cos\phi \cos\theta \tag{21}$$

$$y = \cos\phi \sin\theta \tag{22}$$

$$z = \sin\phi \tag{23}$$

From vector algebra we know that when two vectors are multiplied together vectorially the resultant is called the cross product. The resultant is another vector whose direction is perpendicular to the plane of both of the original

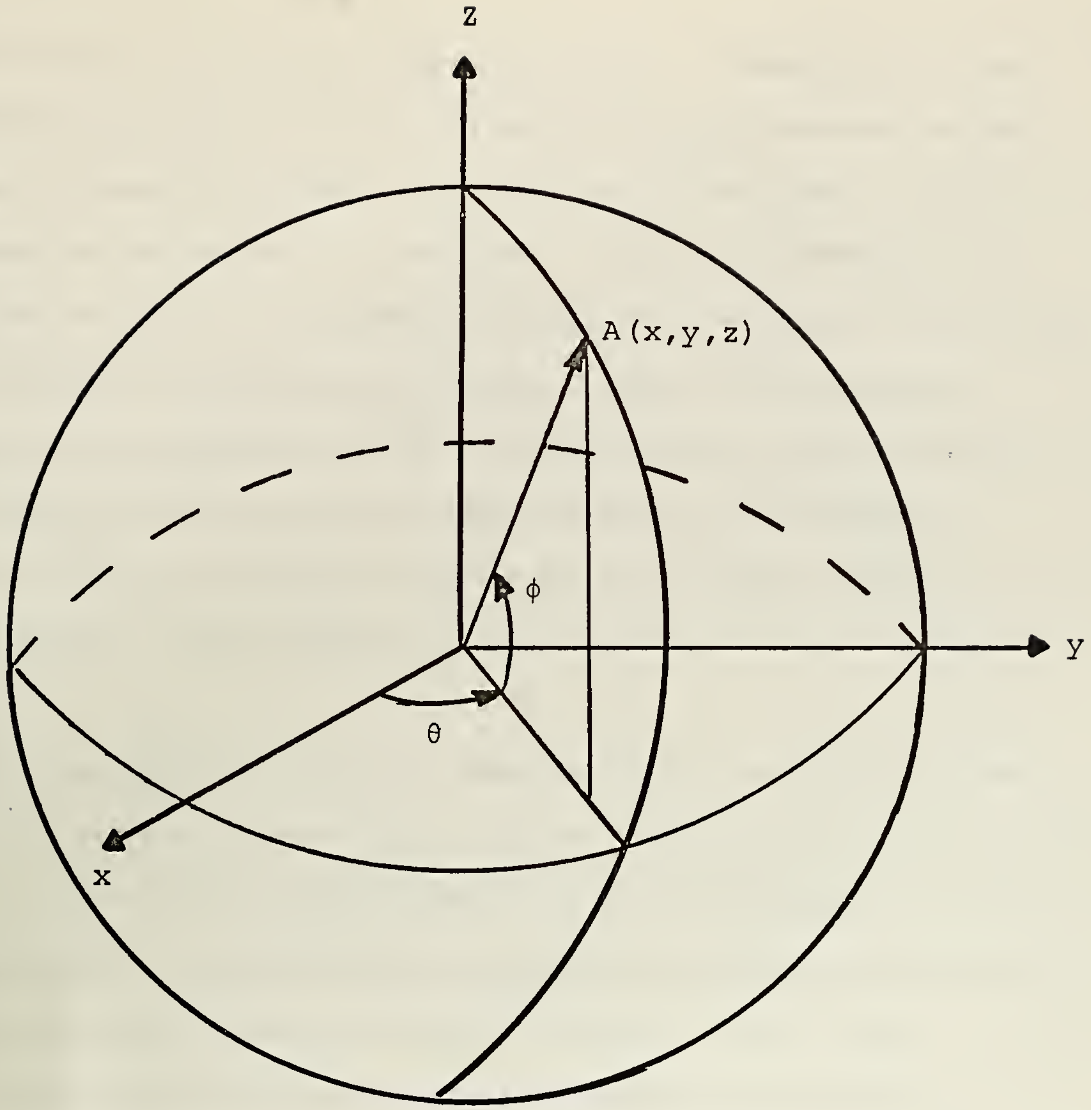

Figure 2. Illustration of Relation Between Station (ϕ,θ) and (x,y,z) coordinates.

vectors and is called the normal vector. Therefore if the aircraft position vector is crossed into the vector normal to the DF bearing plane, a normal vector parallel to the surface of the earth is produced. This multiplication is carried out for the smoothed initial DF bearing, $\hat{\theta}(1|n)$, and the filtered last bearing, $\hat{\theta}(n|n)$. Then if the bearing vectors are assumed parallel to the surface of the earth at the target position, their cross product will produce a vector through the center of the earth at their point of intersection. This vector is the position vector of the target.

The assumption of the DF bearing being parallel to the earth's surface at the target and at the position of the aircraft can be easily understood when it is realized that the bearing vector is actually the projection of the plane containing the DF bearing onto the surface of the earth.

The difficulty of the vector method arises when an attempt is made to describe the bearing vector in an earth centered cartesian coordinate system so the cross product can be obtained. This description is found by a series of three coordinate system rotations. The resultant of a succession of coordinate system rotations is simply the dot product of the coefficient matrices of each rotation [1] and [9].

The rotations made in this program are shown in Figs. 3, 4, and 5. The original coordinate system is denoted (i,j,k), after the first rotation (i*,j*,k*), after the second

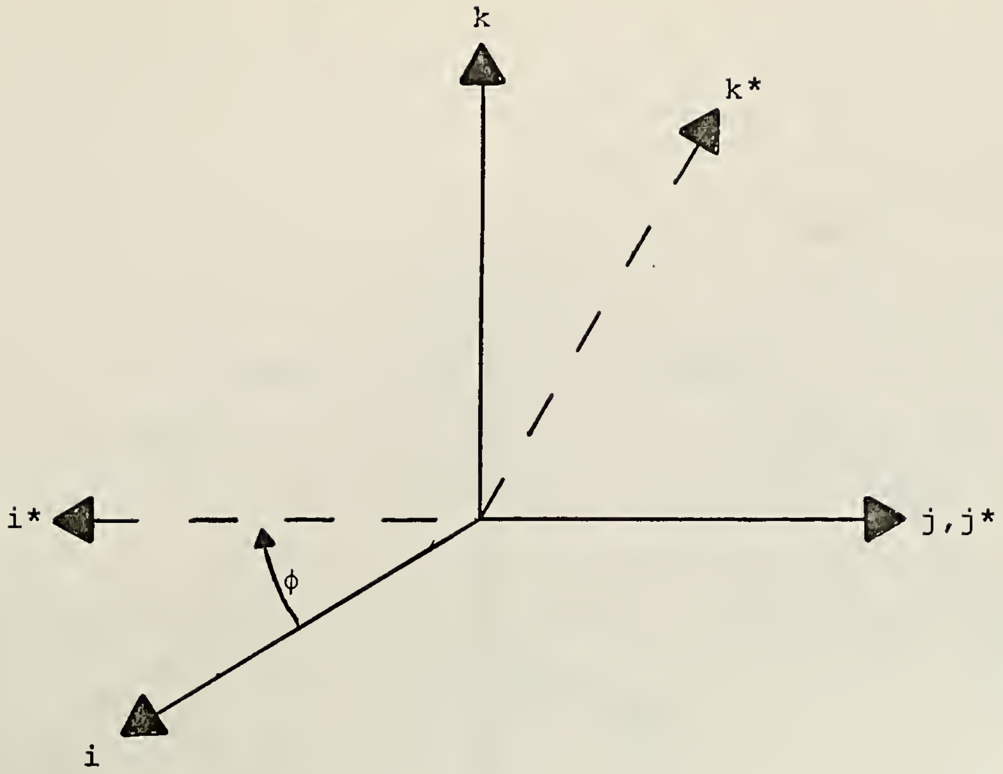

Figure 3. Rotation of Axes about j Axis.

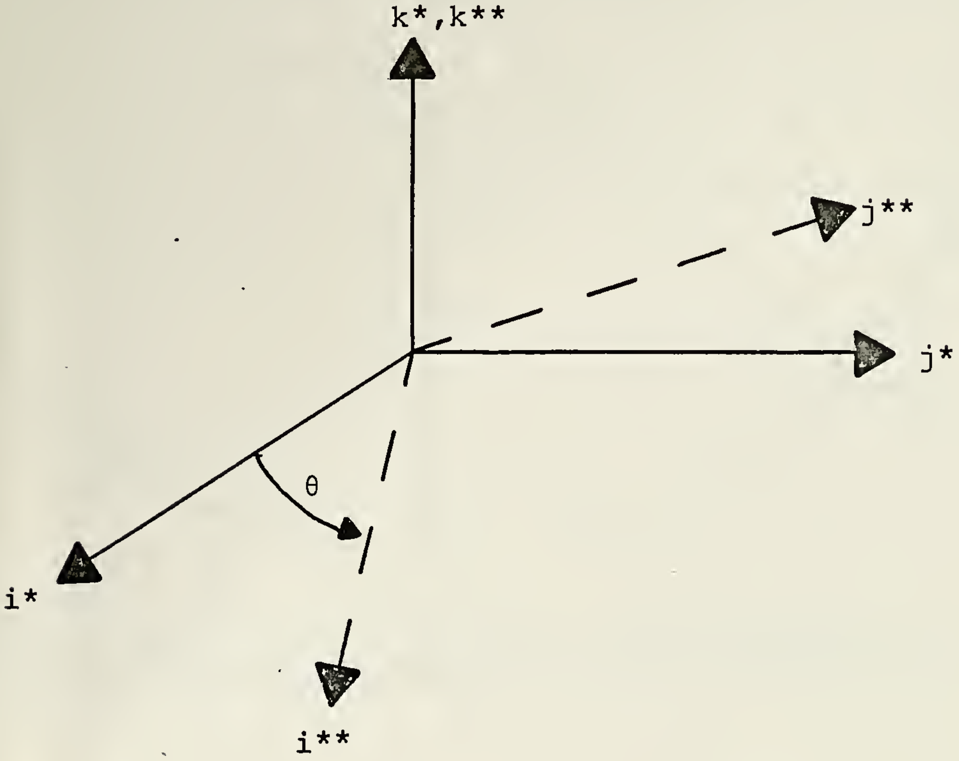

Figure 4. Rotation of Axes about k* Axis.

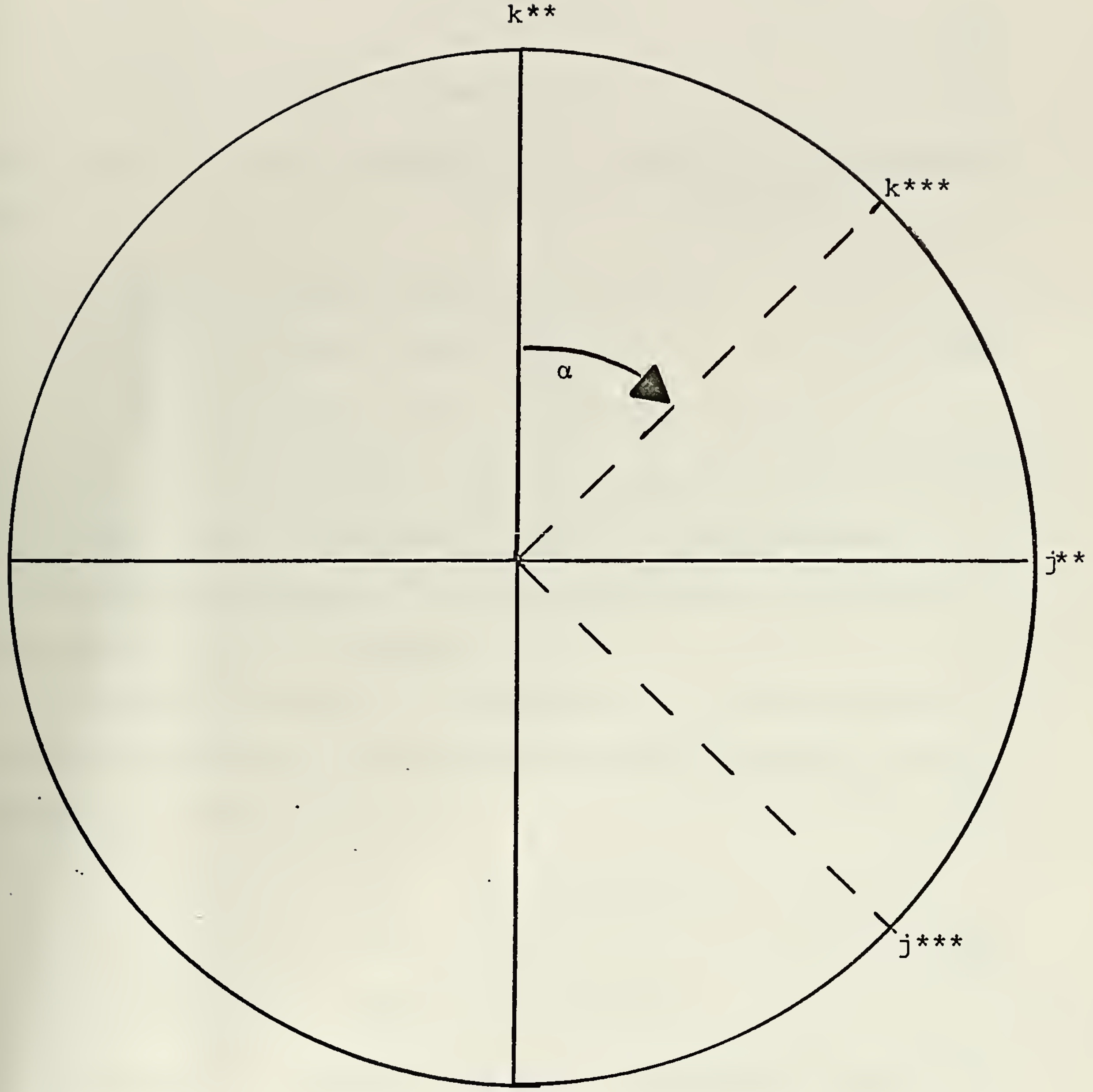

Figure 5. Rotation of Axes About Local Vertical.

rotation (i**,j**,k**), and after the third rotation (i***,j***,k***). The first rotation about the negative j axis is expressed as

$$\begin{bmatrix} i^* \\ j^* \\ k^* \end{bmatrix} = \begin{bmatrix} \cos\phi & 0 & \sin\phi \\ 0 & 1 & 0 \\ -\sin\phi & 0 & \cos\phi \end{bmatrix} \begin{bmatrix} i \\ j \\ k \end{bmatrix} \tag{24}$$

The second rotation is about the k* axis and is represented by

$$\begin{bmatrix} i^{**} \\ j^{**} \\ k^{**} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i^* \\ j^* \\ k^* \end{bmatrix} \tag{25}$$

The resultant of the first two rotations is a target centered coordinate system expressed in cartesian coordinates. In this coordinate frame, i** is local vertical, j** is local west and k** is local north.

The third rotation is a rotation by -α about the i** axis (local vertical) which after making simplifying trigonometric substitutions is

$$\begin{bmatrix} i^{***} \\ j^{***} \\ k^{***} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin\alpha & \cos\alpha \\ 0 & -\cos\alpha & \sin\alpha \end{bmatrix} \begin{bmatrix} i^{**} \\ j^{**} \\ k^{**} \end{bmatrix} \tag{26}$$

Since k*** is the unit vector in the bearing plane, j*** is the normal to the bearing plane and after carrying out the indicated matrix multiplications, is expressed in terms of the original coordinates as

$$N = j^{***} = (-\sin\alpha\sin\theta-\cos\alpha\sin\phi\cos\theta)i + (\sin\alpha\cos\theta-\cos\alpha\sin\phi\sin\theta)j + (\cos\alpha\cos\phi)k. \quad (27)$$

Then by cross multiplying the aircraft position vector associated with N, into N, the vector which represents the DF bearing vector is determined. This method was utilized in developing subroutine POSIT which is discussed in Appendix C.

E. EXTENDED KALMAN FILTER

Since the Kalman filter is optimum only when the system differential equations and measurements are linear, a relationship had to be found to linearize the nonlinear measurements associated with emitter locating. The sought for relationship can be obtained by a Taylor series expansion of the target location. This series expansion of the nonlinear measurements can be substituted for the coefficient matrices in the Kalman filter recursive gain equations and computation then proceeds just as in the discrete algorithm as described previously in this report. This employment of the Kalman filter is frequently referred to as the "Extended Kalman Filter." It is an intuitive but frequently successful application of the Kalman filter in the absence of truly optimum filters for non-linear systems [10].

These techniques are only approximate. They require that the disturbances, measurement noises, and uncertainties in the state be of such a size that the higher-order terms

ignored in computing the error are insignificant. It was felt that for this system, where one of the objectives was simplicity of computation, that though the higher order terms are existent the system dynamics model used was a satisfactory approximation of the actual plant dynamics.

In the case of emitter locating from an aircraft using the extended Kalman filter routine, we are actually filtering in latitude and longitude while our observations are noisy DF bearings only, i.e.

$$Z(k) = \theta(k) + V(k). \tag{28}$$

It is obvious that no pseudo-cartesian coordinates can be generated from this measurement. The non-linear measurement process must therefore be represented by a linear approximation.

From the development of the Kalman filter equations [6], it can be seen that

$$\hat{X}(k|k) = \phi(k,k-1)\ \hat{X}(k-1|k-1) + E[\hat{X}(k|k)|\hat{Z}(k)] \tag{29}$$

Let $G(k)\hat{Z}(k) = E[\hat{X}(k|k)\hat{Z}(k)]$ where $\hat{Z}(k) = M(k)\hat{X}(k|k-1)$. So the estimated measurement equation becomes

$$\hat{Z}(k) = \hat{\theta}(k) \tag{30}$$

where [2]

$$\hat{\theta}(k) = \mathrm{TAN}^{-1}\left(\frac{(\lambda_T-\lambda)\ \cos\ L_T}{L_T - L}\right) \tag{31}$$

where λ_T is the target longitude, λ is the aircraft longitude, L_T is the target latitude, and L is the aircraft latitude.

Substituting this expression into the Kalman filter equations, the recursive filter equation becomes

$$\hat{X}(k+1) = \phi(k+1,k)\hat{X}(k) + G(k)[\theta(k) - \hat{\theta}(k)]. \tag{32}$$

Expanding the measurement equation

$$\hat{\theta} = M(\lambda,L) \tag{33}$$

about the most recent optimal estimate and ignoring higher order terms results in

$$\hat{\theta} = M(\lambda^*,L^*) + \frac{\partial\hat{\theta}}{\partial\lambda}\bigg|\lambda^* + \frac{\partial\hat{\theta}}{\partial L}\bigg|L^*. \tag{34}$$

from which we see that

$$M = \begin{bmatrix} \frac{\partial\hat{\theta}}{\partial\lambda} & \frac{\partial\hat{\theta}}{\partial L} \end{bmatrix} \tag{35}$$

The Kalman filter recursion equations, (7) through (11), may then be rewritten to include the nonlinear observation matrix M, and are given by

$$P(k|k-1) = \phi(k,k-1)P(k-1|k-1)\phi(k,k-1)^T + Q(k) \tag{36}$$

$$G(k) = P(k|k-1)M(k)\left[M(k)P(k|k-1)M(k)^T + R(k)\right]^{-1} \tag{37}$$

$$P(k|k) = P(k|k-1) - G(k)M(k)P(k|k-1) \tag{38}$$

$$\hat{X}(k|k) = \hat{X}(k|k-1) + G(k)\left[Z(k) - M(k)\hat{X}(k|k-1)\right] \tag{39}$$

$$\hat{X}(k|k-1) = \phi(k,k-1)\hat{X}(k-1|k-1) \tag{40}$$

III. COMPUTATIONAL PROCEDURES

A. NAVIGATIONAL DATA FILTERING - (SUBROUTINE NAV)

The first step in the problem of finding a target is that of filtering the aircraft position estimates. Aircraft navigation data was sampled and recorded at discrete but time varying intervals. As stated in Section II, part B.1, only the position fixes were measured so the velocity is only estimated and is strictly a product of the model used to represent the aircraft. Since the aircraft position fixes were taken at random intervals, there are extended periods during which no navigation data is available and when the flight track could be altered drastically. Therefore, the flight track is broken into legs to ensure that the program does not attempt to filter through these abrupt changes.

The criteria used in this program to establish the end of a leg is a simple time test. If T(k), the time between navigation fixes, exceeds 120 seconds, the current leg is terminated and a new leg is initiated.

If a leg was found to consist of three or fewer data points, that leg was neither filtered nor smoothed, but rather the measured data was used for the filtered and smoothed estimate of position, i.e., SLADSM(K)=ACLAD(K). No estimation of velocity was computed for these legs. After the entire flight track was divided into legs, the Kalman filter was initialized.

The navigation data filter consists of two nearly identical Kalman filters, one to filter latitude and the other for longitude filtering. The system dynamics for the aircraft are modeled in each direction by a constant velocity plant.

Since equal angles of latitude and longitude yield equal distances of movement only at the equator, a correction factor must be applied to angular measure as either pole is approached from the equator.

At 60 north latitude, for example, one degree of movement in latitude measures sixty nautical miles while one degree of movement in longitude only measures thirty nautical miles. This requires that the longitude angular distance be corrected by the cosine of the local latitude coordinate so that the two filters will have equal units of distance. The position estimates of the navigation data filters are based on estimated distances traveled, i.e.

$$\hat{X}1(k|k) = \hat{X}1(k|k-1) + \dot{\hat{X}}1(k|k-1)\ T(k) \qquad (41)$$

The estimated changes in longitude position will be off by a value of 1/cos(latitude), so (41) was modified to

$$\hat{X}1(k|k) = \hat{X}1(k|k-1) + \dot{\hat{X}}1(k|k-1)\ T(k)\cos(\text{latitude}) \qquad (42)$$

Equivalently, $\dot{\hat{X}}1(k|k-1)$ can be reduced by the cosine of the latitude directly, which is the method used in this program. The equation used in NAV then is

VELED(K)=(VELED(KK) + G2(K)*ELON(K))*COS(SLA(K)) (43)

where VELED is the aircraft velocity east in degrees per second, G2 is the Kalman filter gain, ELON is the Kalman filter error term and SLA is the latitude coordinate of the aircraft. The same correction is applied to the smoothed $\hat{X}1(k)$ term, VELEDS, in the smoothing filter.

To initialize the latitude filter, the initial position estimate, SLAD(KI), was set equal to the first measured position, ACLAD(KI). The aircraft velocity was not observable, so the initial velocity was estimated by

$$\text{VELND(KI)=(ACLAD(KI+1) - ACLAD(KI))/T(KI+1)} \tag{44}$$

where T(KI+1) is the time increment from time KI to time KI+1. $\hat{X}(1|0)$ was assumed equal to $\hat{X}(0|0)$ so SLATD(KI), the predicted value of SLAD, was also set equal to ACLAD(KI).

The longitude filter was initialized in the same manner as the latitude filter with the only change being that the velocity east was corrected by the cosine of the latitude to correct for the curvature of the earth as discussed above. Therefore

$$\begin{aligned}\text{VELED(KI)=((ACLOD(KI+1) - ACLOD(KI)/T(KI+1))}\\ \text{X COS(SLA(KI))}\end{aligned} \tag{45}$$

The initial uncertainty of position and velocity on filter initialization was accounted for in the initial values of the error covariance matrix P(1|0). The error in the initial position fixes by the navigational computer were assumed to be very small and so the initial covariance matrix P(1|0), was set equal to the identity matrix.

The measurement noise, v, is assumed scalar so by (3)

$$E\left[vv^T\right] = R. \tag{46}$$

The value of R will change for each system, depending upon the accuracy of that system, but it is assumed constant for each data set.

The smoothing filter is recursive in negative time so the first estimate of position computed by the smoothing filter is the next to the last fix in that leg. Therefore to initialize the smoothing filter, the first smoothed estimate SLADSM(N), was set equal to the last filtered position estimate SLAD(N). The error covariance matrix P, used to compute the smoothed position estimates is the same matrix computed for the Kalman filter, so there was no P matrix to initialize.

It was found that occasionally the aircraft navigational computer would produce a totally erroneous position fix, to check for this occurrence, each Kalman filter error term, $E(k) = Z(k) - \hat{X}(k+1|k)$, was checked and if it exceeded a certain value, denoted test, the data point was rejected. The estimate of the state, $\hat{X}(k+1|k)$, was inserted as the estimate of position, i.e. in the latitude filter

$$\mathrm{SLAD}(K)=\mathrm{SLAD}(K-1) + \mathrm{VELN}(K-1)T(K) \tag{47}$$

The equations used in the navigation data filter (SUBROUTINE NAV) are derived in Appendix A.

B. ANGLE FILTERING - (SUBROUTINE GEORGE)

After the navigation data is filtered and smoothed the processing switches to subroutine GEORGE, which is basically the program presented in [2], This subroutine sorts the emitter data and then filters and smooths the DF bearings.

To adapt the program presented in [2], for use in this problem, the data sort routine was changed, a new smoothing filter was inserted and the emitter position locating algorithm was replaced by a vector solution method which is included in subroutine POSIT.

The data sort used in this program is shorter than the original routine. In the data sort routine, the error interval associated with the measured values of signal frequency and PRF was opened up to approximate the errors of the system being simulated. This test interval can easily be changed to any desired width to fit the system being simulated.

It was found that the PRF value was zero in some data sets. In these cases, the DF bearing associated with these particular points were correlated with the previous signal with the same carrier frequency.

All of the DF bearing angles are checked for target correlation as in [2], but instead of discarding any data points which do not pass the test $E^2(K)<(P11(K) + RCUT)*TSTCUT$, being discarded, they are assigned to a new target. RCUT is the assumed value of the variance of the measurement noise v, and TSTCUT is a multiplier to vary the

size of the gate. This routine was inserted because with the method used in [2], only one target of each FREQ and PRF could be processed from each data set; data from all other similar emitters were discarded.

The smoothing routine utilized here is shorter and does not require the computation of the inverse of the P matrix as was required in [2], since computing the inverse of a matrix consumes a lot of computer time. The smoothing filter equations used are derived in Appendix B.

After each DF bearing, THTD(K), is filtered and the first DF bearing, THTD1(k), is smoothed based on all successive bearing estimates, a test is made to determine if processing should be switched to extended Kalman filtering, which is done in subroutine EXTEND. This test compares P11(K) with the product of EXTEST and RCUT, where EXTEST is a multiplier to vary the size of the gate. If EXTEST is set equal to zero, the processing will always stay in the angle filter. As EXTEST is increased the processing will switch to EXTEND earlier and earlier in the data sequence but the initial estimate of the target position used to initialize the extended filter will be worse, as will the initial value of the P matrix in the extended filter equations described in part F of this section.

If it is decided that all of the DF bearings correlated to a target will be angle filtered, GEORGE calls subroutine PREPARE which in turn calls subroutine POSIT which computes the emitter location based on the DF bearings THTD1 and

THTD directly. These subroutines are discussed later in this section.

The value of the multipliers of both tests in GEORGE, TSTCUT and EXTEST, are calling arguments for the subroutine so they can be controlled by the main program.

All of the Kalman filter initializations for GEORGE are discussed in [2]. The fixed delay smoothing equations are initialized with the initial smoothed estimate THTD1(1), being set equal to the initial filtered estimate THTD(1). THTD(1) was set equal to the measured value of the first DF bearing, THETAD(KI).

C. SUBROUTINE PREPARE

When vector products are used, the order of multiplication is critical; if the order is reversed, the resultant will be reversed. In the problem of emitter position locating, a reversed resultant will produce a fix on the opposite side of the earth. PREPARE is written to prevent this occurrence. First the direction of the track of the aircraft is computed. Then THTD and THTD1 are checked to determine on which side of the track they lie and ensure that they both lie on the same side of the track. If they do not, no position fix is calculated. If they do lie on the same side of the track, they are checked to see if they cross. If not, no fix is computed. PREPARE then computes the calling arguments for POSIT - ACLAD, ACLON, and THD. ACLAD and ACLON are the latitude and longitude coordinates respectively of the aircraft at the times the two DF bearings

were recorded. THD contains the direction of the two bearings THTD1 and THTD. In so doing, it ensures that the DF bearing with the larger angle of arrival is crossed into the bearing with the smaller angle of arrival and not vice versa. PREPARE is also called by ELIPS6 and EXTEND.

D. COMPUTING INITIAL POSITION - (SUBROUTINE POSIT)

POSIT then computes the desired location by the method described in Section II, part D. First the bearing vectors, $\underline{\hat{\theta}}(1|n)$, and $\underline{\hat{\theta}}(n|n)$, are expressed in the earth centered cartesian coordinate system. Then the cross product of the two bearing vectors is computed giving the target vector in x, y, z coordinates. These coordinates are converted to latitude and longitude coordinates by

$$\mathrm{TLAD} = \mathrm{TAN}^{-1}\left(\frac{X3}{\sqrt{X1^2+X2^2}}\right) \tag{48}$$

$$\mathrm{TLOD} = \mathrm{TAN}^{-1}\left(\frac{X2}{X1}\right) \tag{49}$$

where X1, X2, and X3 are the x, y, z coordinates respectively. An example illustrating the method used to find the target vector is given in Appendix C.

E. DEFINING THE ERROR ELLIPSE - (SUBROUTINE POINTS)

If it is decided that the data should be processed by the extended Kalman filter, POINTS is first called. POINTS uses POSIT to compute the intersections of the edges of the cones of error associated with THTD and THTD1. These points are shown in Fig. 6. POINTS ensures that PTLAT(1,I,J),

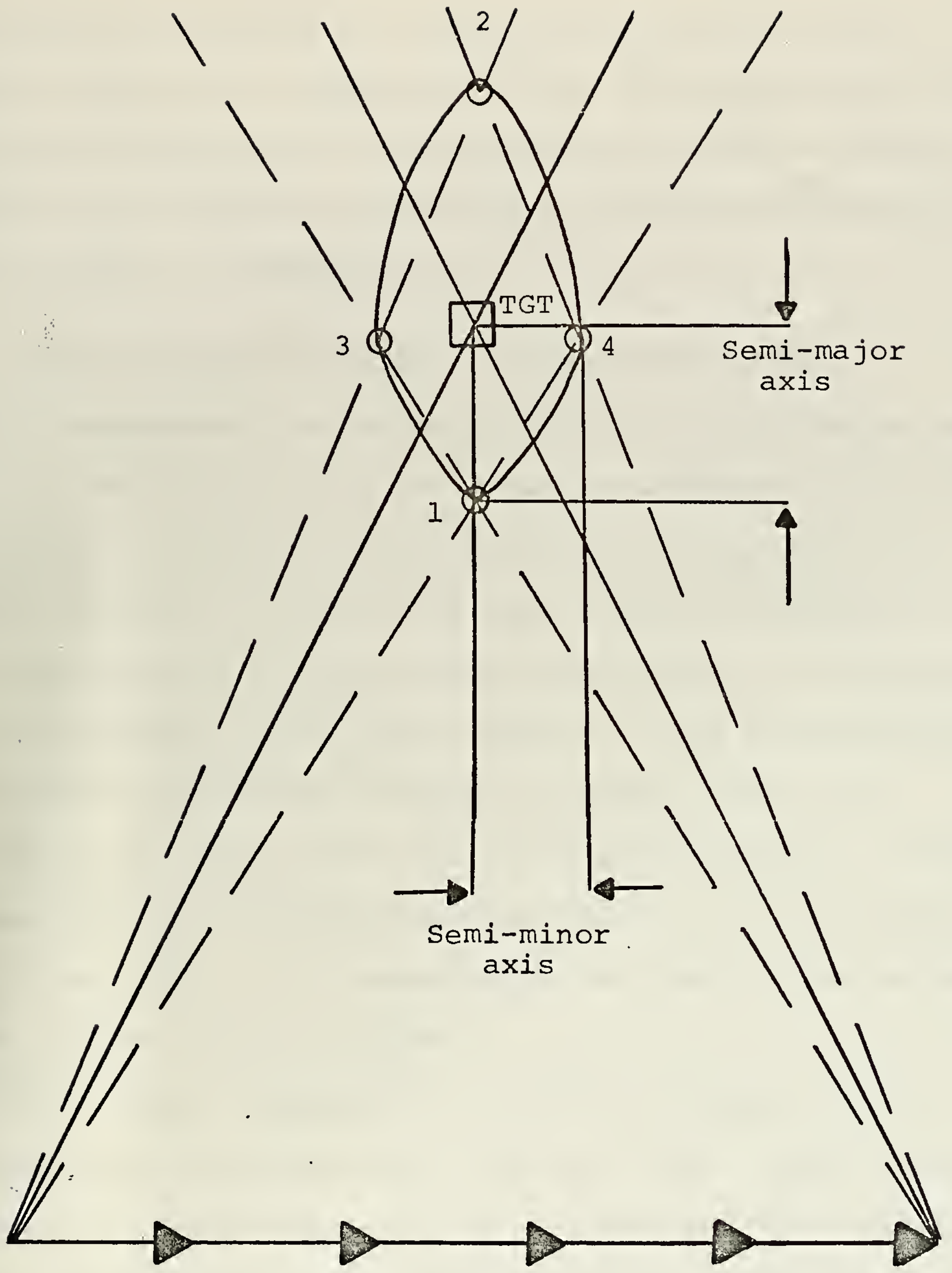

Figure 6. Target Position Error Covariance Ellipse.

PTLON(1,I,J) is always the intersection closest to the flight track and it determines if the DF bearings THTD1 and THTD do in fact cross. If they do not, it makes sure that EXTEND is not called by returning to the calling program at a point after the EXTEND call.

F. EXTENDED KALMAN FILTERING - (SUBROUTINE EXTEND)

In linearizing the system by using a Taylor series expansion, it was assumed that the M matrix would be fairly constant over the range of uncertainty of x, therefore the initial value of x, $\hat{x}(0)$, must be a good approximation of the true value of x or the filter can diverge. To find an initial estimate of the true value of x, the DF bearings are first angle filtered in subroutine GEORGE. When the covariance of error of the current bearing estimate, P11(K), becomes less than EXTEST times the variance of the measurement noise, RCUT, the processing is switched to the extended Kalman filter routine, EXTEND.

EXTEND calls PREPARE for an initial estimate of the target position coordinates, TLAD, and TLOD. EXTEND then computes the semi-major axis, a, and the semi-minor axis, c, of the error covariance ellipse described by the coordinates from POINTS and centered at the coordinates computed by PREPARE.

The length of the semi-major axis of the error ellipse was assumed to be the distance from the initial target location, TGT, to the intersection of the error cones closest to the flight track. These points are shown in Fig. 6.

The length of the semi-minor axis is found in the following manner.

The distance from the target position, TGT, to point 3 and the distance from TGT to point 4 are computed. The projection of the average of these two distances on to a line perpendicular to the semi-major axis is the length of the semi-minor axis.

The orientation of the error ellipse on the surface of the earth is taken to be the amount of clockwise rotation of the semi-major axis from the meridian passing through the center of the ellipse.

A and c uniquely describe an ellipse in an x' y' coordinate frame according to

$$\frac{x^2}{c^2} + \frac{y^2}{a^2} = 1. \tag{50}$$

The x'y' system is rotated by an angle (90-α) degrees from the xy system in which the extended Kalman filter functions. The x and y axes correspond to longitude and latitude respectively on a flat earth model. The extended filter will find an optimal estimate of the coordinates of the emitter position in the xy system. To describe the error ellipse in the xy system, a coordinate system rotation was made according to the transformation matrix.

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} x' \\ y' \end{bmatrix} \tag{51}$$

After performing this transformation and making simplifying trigonometric substitutions (see Appendix D) the initial values for the covariance matrix P, become

$$P11(KI) = (A \sin\alpha)^2 + (C \cos\alpha)^2 \tag{52}$$

$$P12(KI) = (A^2-C^2) \sin\alpha\cos\alpha \tag{53}$$

$$P22(KI) = (A \cos\alpha)^2 + (C \sin\alpha)^2 \tag{54}$$

Using (31), EXTEND computes an initial estimate of $\hat{\theta}$, TX, which is used to compute the initial extended filter error term, ER(KI)=THETA(KI)-TX(KI), where THETA is the measured DF bearing angle in radians. The initial gains associated with the nonlinear measurement equation are found from (37). The initial estimate of longitude, XTD, is set equal to TLOD, and YTD, the initial value of latitude, is set equal to TLAD.

The initial inputs to the linear longitude and latitude filter, XTD1 and YTD1, are then found by substituting (11) into (10), rewritten as

$$XTD1(KI)=XTD(KI) + GX(KI)ER(KI) \tag{55}$$

$$YTD1(KI)=YTD(KI) + GY(KI)ER(KI). \tag{56}$$

Then the outputs, XTD and YTD, of the linear filters are fed into the linearized filter and the process proceeds as described for initialization.

The longitude and latitude filter equations are identical to the corresponding filters in subroutine NAV except for notation, as listed in Appendix A.

The Φ matrix for the linearized measurement filter is the identity matrix since the states of this filter are longitude and latitude only.

On each recursion of the filter the error term ER, is compared with a gate identical to the correlation gate in subroutine GEORGE. Any DF bearings failing the test are assigned to a new target and are processed either in the angle filter or in EXTEND on a later call of the subroutine. The extended Kalman filter equations are derived in Appendix D.

IV. PRESENTATION OF RESULTS

The Monte Carlo simulation developed in [2] was utilized to accomplish program validity and error analysis studies. The scenario developed for that simulation was of an aircraft flying south along the 118°W meridian at a ground speed of 600 knots and with heading of 180°. Bearing angles-of-arrival were recorded from two VORTAC stations located at

Emitter 1	Oceanside VORTAC	33.24055°N 117.41694°W
Emitter 2	San Diego VORTAC	32.78222°N 117.22444°W

DF cuts and aircraft position fixes were recorded every six seconds alternately from each target giving a uniform sampling interval. Known true bearing angles were computed numerically from the aircraft position coordinates and the emitter position coordinates to obtain a very accurate data base. The DF cuts obtained are shown in Fig. 7 for emitter 1 and in Fig. 8 for emitter 2.

Normally distributed, zero mean random noise with an assumed variance of 1 was added independently to the latitude fixes, longitude fixes, and angles-of-arrival. The errors in aircraft heading and angle-of-arrival were combined into the single angle-of-arrival error. The flight track and noisy DF bearings are shown in Figs. 9 and 10 for emitters 1 and 2 respectively.

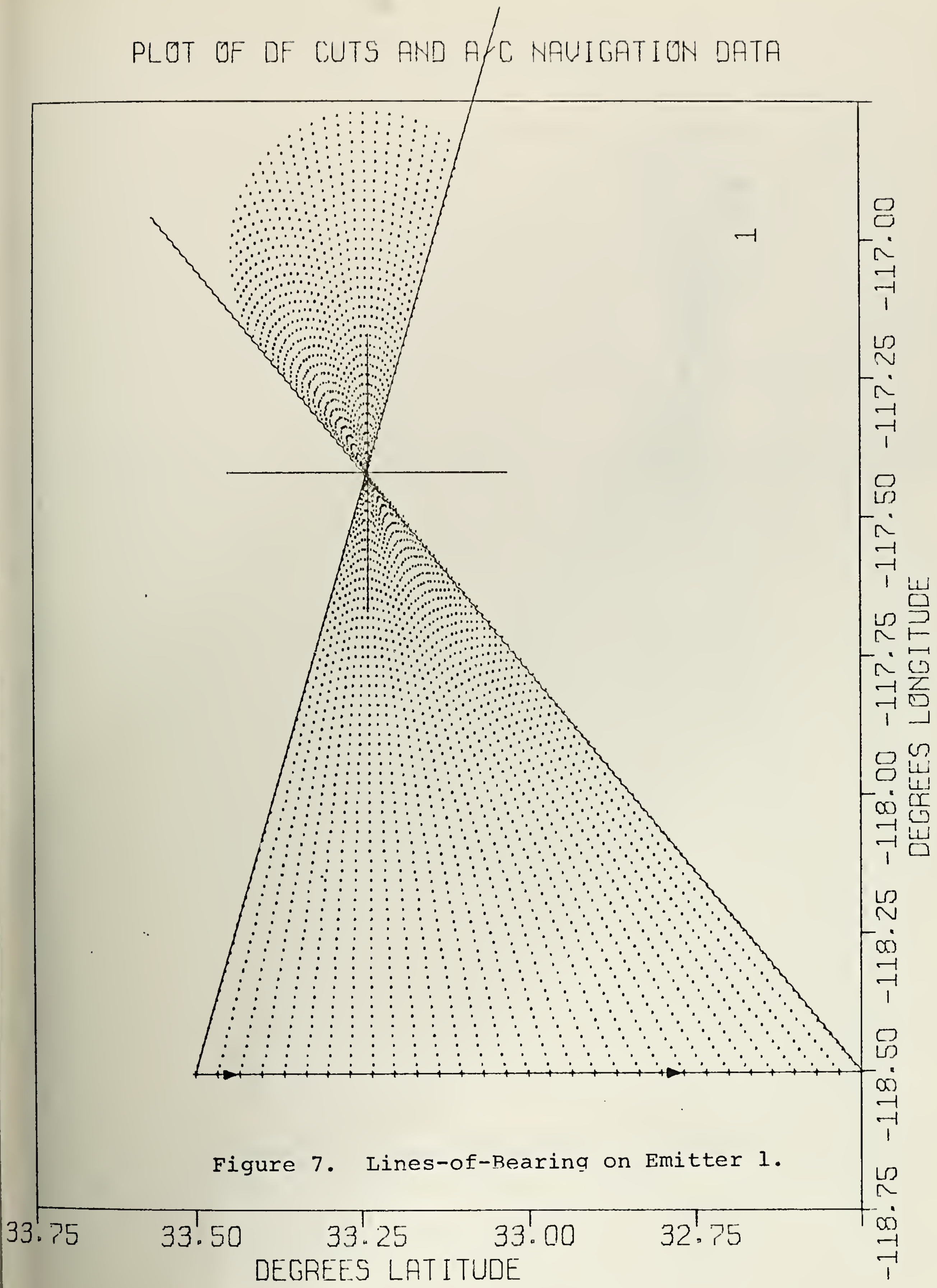

Figure 7. Lines-of-Bearing on Emitter 1.

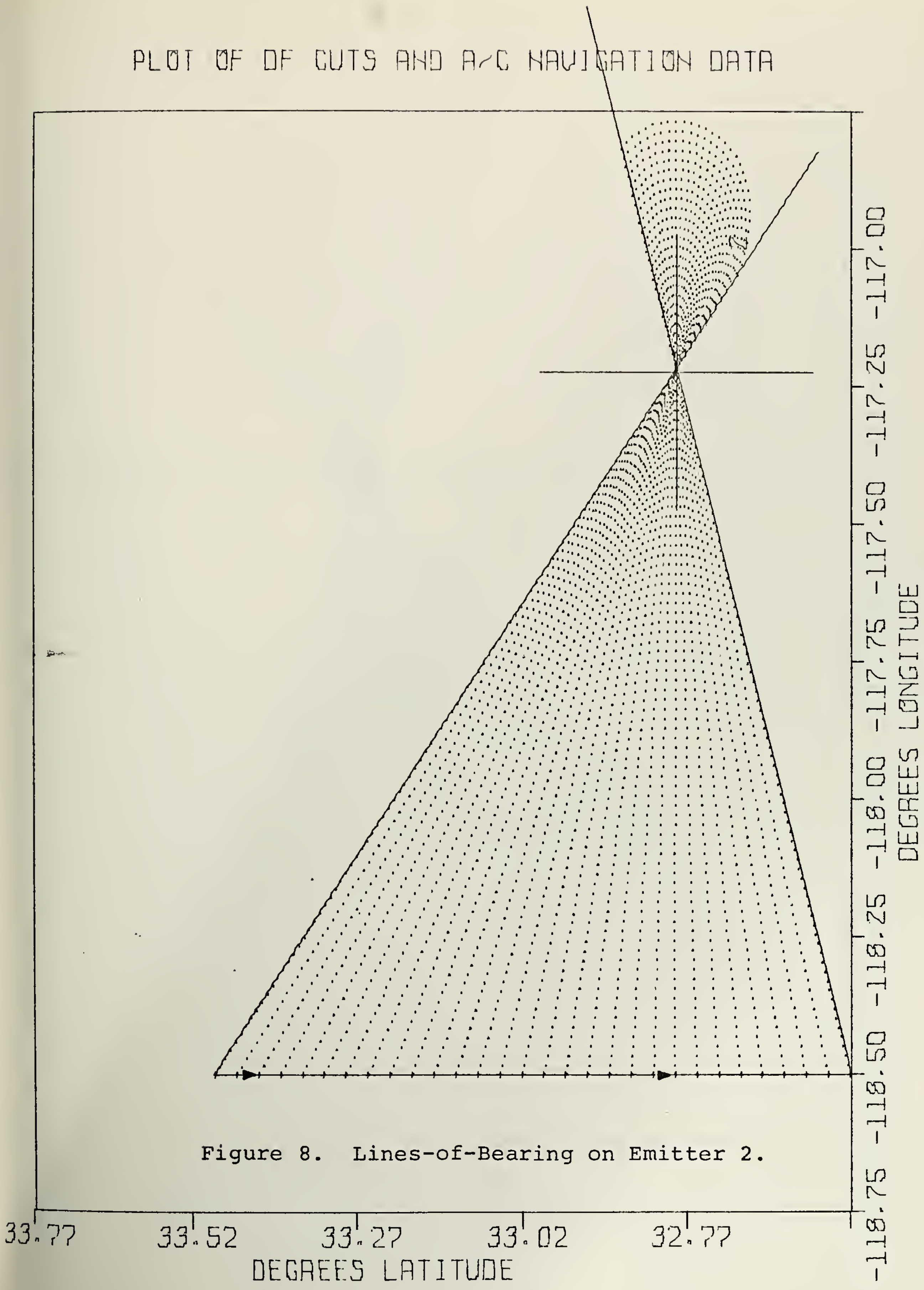

Figure 8. Lines-of-Bearing on Emitter 2.

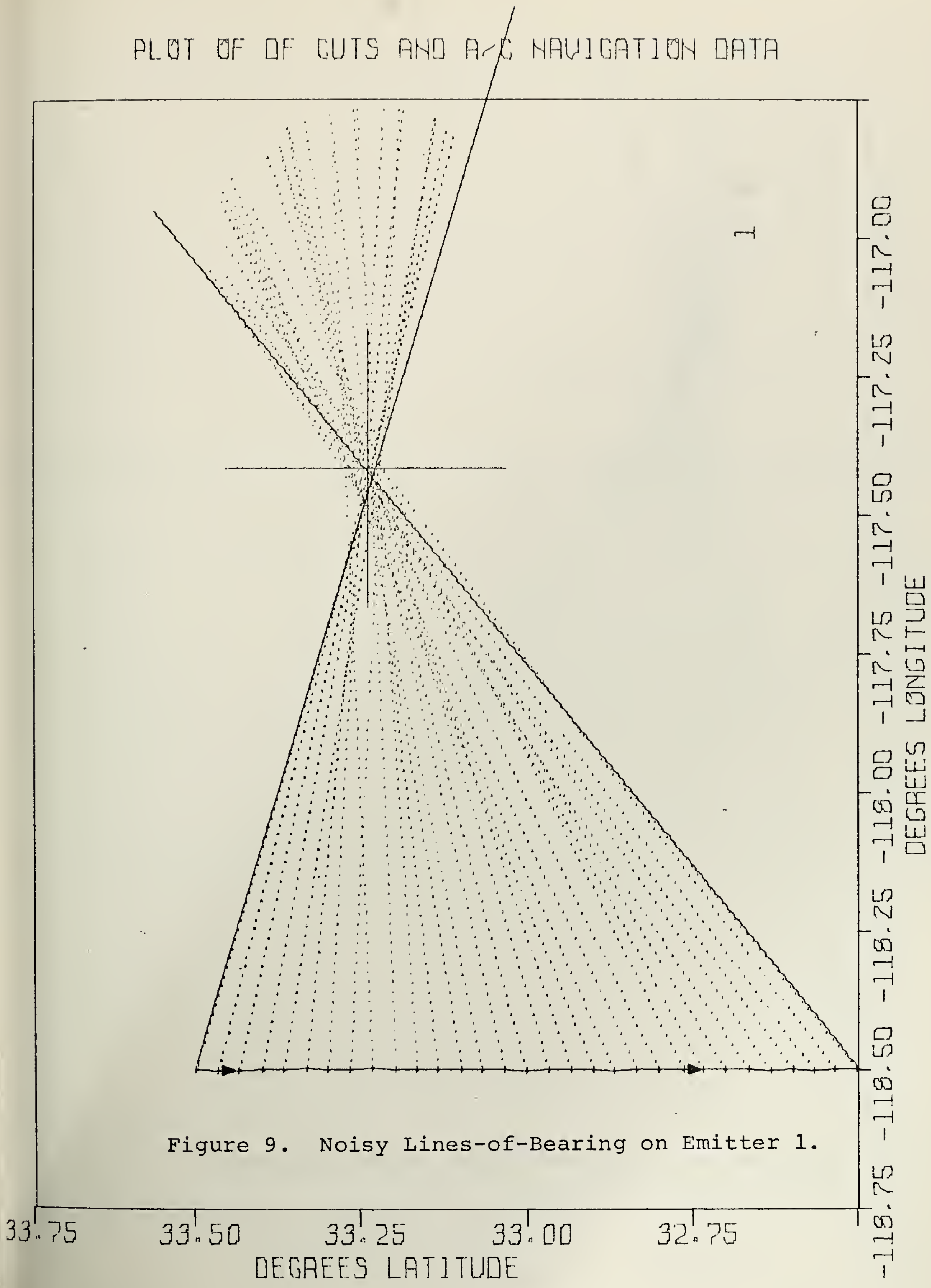

Figure 9. Noisy Lines-of-Bearing on Emitter 1.

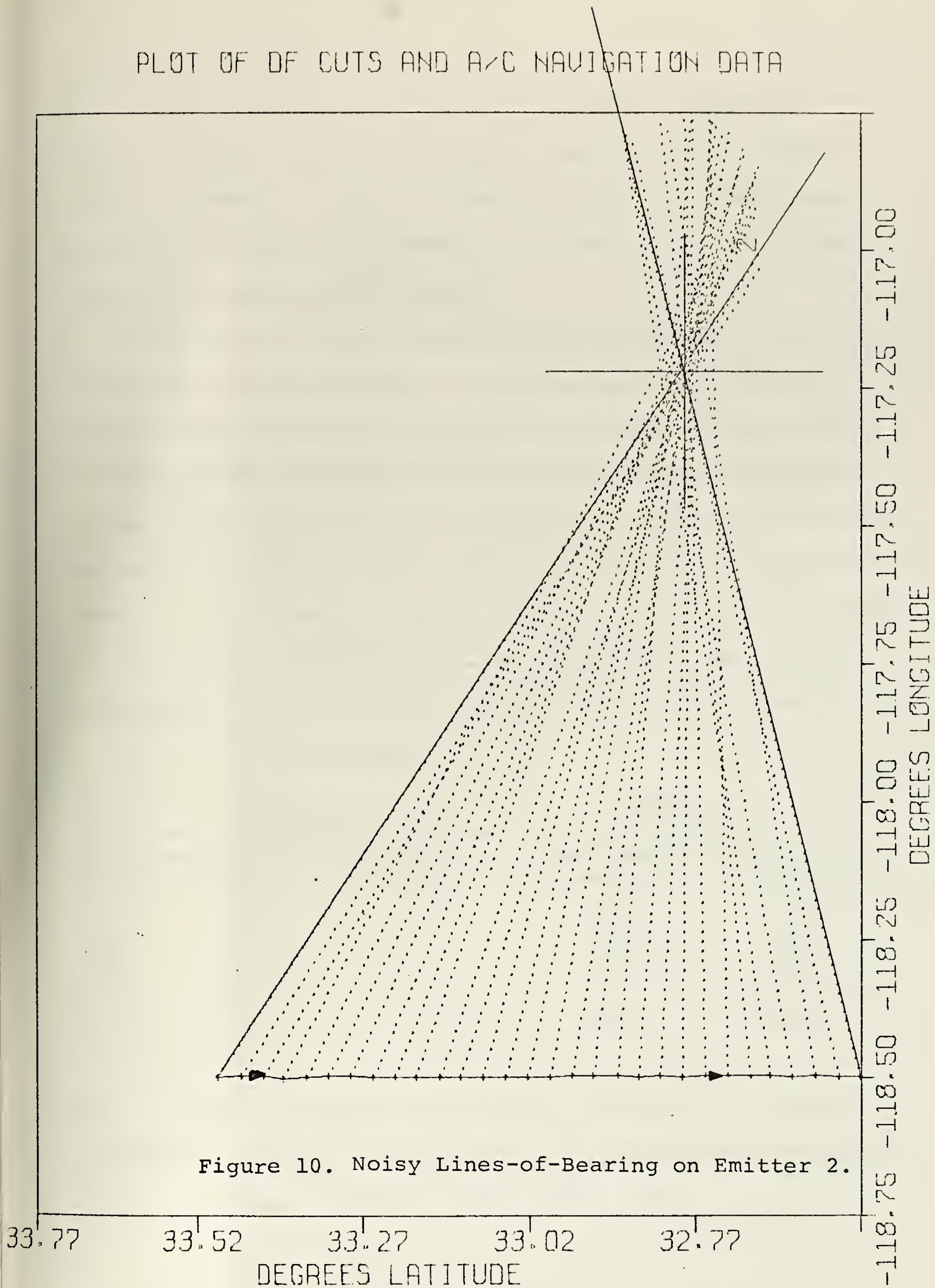

Figure 10. Noisy Lines-of-Bearing on Emitter 2.

A. ERROR ANALYSES

A large number of simulation runs were executed to obtain a statistically valid error analysis, where each run constituted a complete mission. The results of these analyses are given in Appendix E and are summarized below for the two simulation emitters.

The results of the error analysis of the navigation data filter are listed on page . The average of the noise added to the positions is shown as is the mean-square value of that noise. By comparing the listed mean-square error of the positions with that of the noise, it can be seen that the model utilized in the program has a bias which develops after a large number of runs. Each run is a complete flight of 61 position fixes, so the result after 45 runs is the statistical average of 2745 data points. The results of 2, 10, 45, and 50 runs was found to be

	LATITUDE		LONGITUDE	
Runs	Mean-Square Noise	Mean-Square Error	Mean-Square Noise	Mean-Square Error
2	.427	.326	1.80	1.21
10	.937	1.02	1.24	1.16
45	1.26	1.37	1.19	1.24
50	1.19	1.31	1.14	1.23

The units for this list are degrees times 10^{-8}. The error associated with each individual position fix on a single run is shown on page .

For the analysis of the angle filter, a range error was computed from each estimated emitter position latitude error and longitude error, and all errors were statistically averaged for the total number of runs.

The longitude error which is perpendicular to the flight path was found to be much larger than the latitude error. This result agrees with the theory used to develop the ellipses which describe the initial covariance matrix for the extended Kalman filter. This result also agrees with the final orientation of the target error ellipses as shown on page 51 and 52. The results of this analysis are summarized below for 50 runs.

	AVERAGE LATITUDE ERROR	AVERAGE LONGITUDE ERROR	AVERAGE RANGE ERROR
EMITTER 1	.684	1.129	1.391
EMITTER 2	.685	1.870	2.098

The units of the above table are nautical miles.

The results of the error analysis of the extended Kalman filter are shown on page 73. The errors of each individual flight which are listed on that page point out the dependency of this filter on the accuracy of the initial estimate of the emitter position. Since the initial estimate is based on only four DF bearings for this simulation, this estimate is heavily weighted by the noise added to the first bearings and the rate of convergence of the filter. The results of the

analysis of the extended filter are given below for 50 runs with the units being nautical miles.

	AVERAGE LATITUDE ERROR	AVERAGE LONGITUDE ERROR	AVERAGE RANGE ERROR
EMITTER 1	1.535	4.654	4.988
EMITTER 2	.872	7.784	7.876

B. COMPUTER PROCESSING OF SIMULATED DATA

A series of plots showing the ability of this program to locate target positions in the absence of noise starts on page 50. The number in the lower right corner is the number of the DF bearing estimate associated with that target which was used to compute the target position and error ellipse in that plot. The plots on page 51, 52 and show the four points of intersection computed by POINTS which describe the error ellipse. From these plots, it can be seen that the error ellipse does accurately describe the area of the probability region associated with each position fix.

The output of a single run of the program using the simulated data starts on page 76. The first run assumes that processing will be strictly by the angle filter. The output of a run in which the extended filter was utilized starts on page 110. Plots of the error ellipses associated with the covariance matrices of each filter are included in the output.

These series of plots show the change of orientation of the error ellipse as the aircraft progressed along its flight

path. They also illustrate the decrease in area of the ellipses as more data is collected and as the angle between the smoothed initial bearing $\hat{\theta}(1/N)$, and the filtered final bearing $\hat{\theta}(N/N)$ increased.

By comparing the plots of the ellipse associated with the angle filter on page 50 and the plot on page 53 associated with the extended filter, it can be seen that the extended filter is initialized with the same error covariance as the angle filter.

Further comparison of the two series of plots shows that the position of the centers of the ellipses produced by the angle filter are much more erratic than those of the extended filter. This indicates that the angle filter has a faster response to each new bit of data than the extended filter. The response may seem too fast, but in order to have a rapid rate of convergence of the filter so processing could switch quickly to the extended filter, fast response is necessary, so this is a compromise.

The slow response of the extended filter is shown by the relatively slow rate of rotation of the error ellipse. The slow response is desirable to prevent the filter from converging too rapidly onto a wrong point if it is initialized with a poor initial position fix.

C. AIRCRAFT FLIGHT DATA PROCESSING

The output of a computer run using data from an actual flight starts on page 144. The effectiveness of the data

sort routine is shown by the lists on page 146 and 147. The first list is the result of the sort on PRF and FREQUENCY only. The second list is the final correlation after the data has been correlated to targets using the test discussed on page 31.

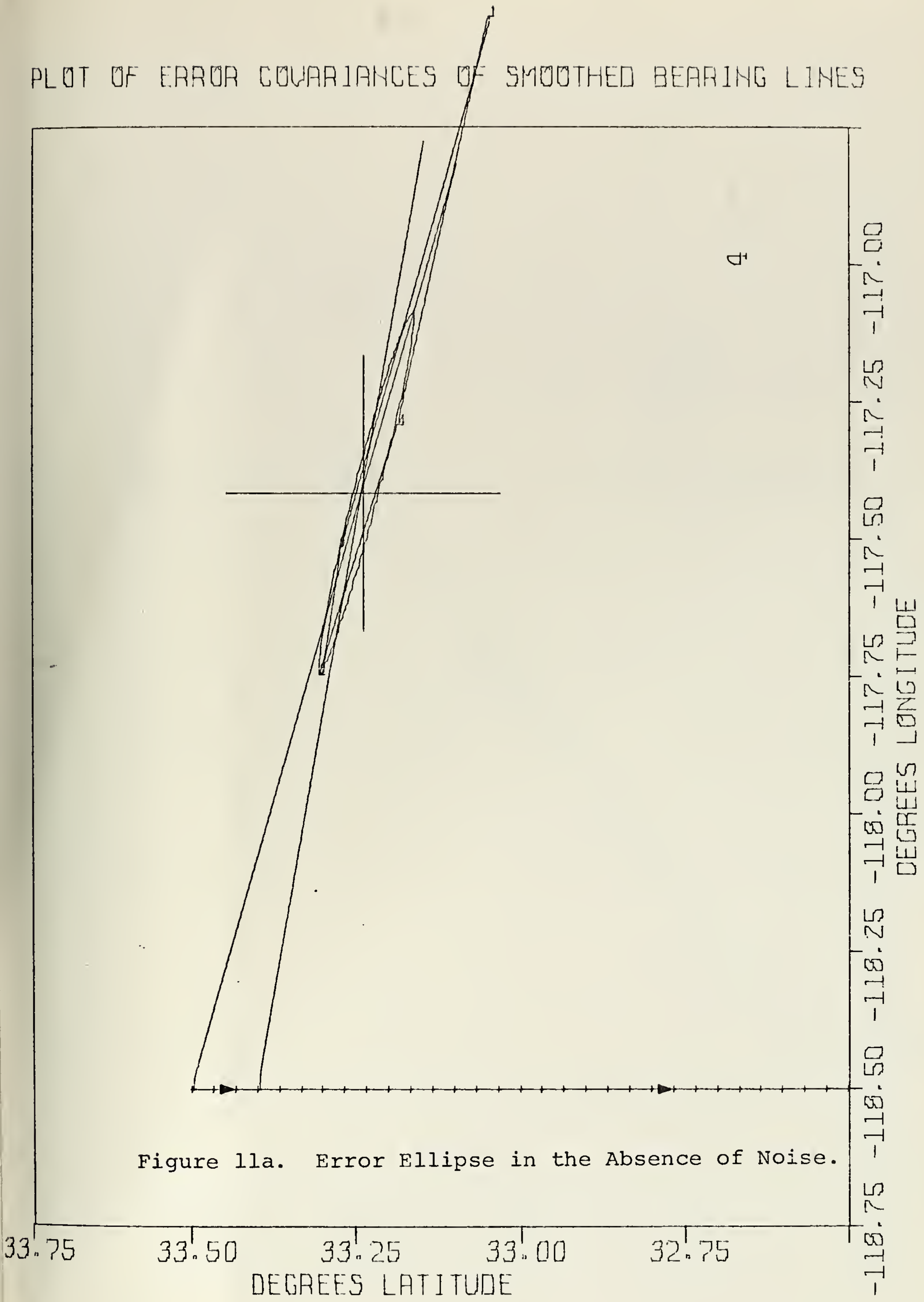

Figure 11a. Error Ellipse in the Absence of Noise.

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

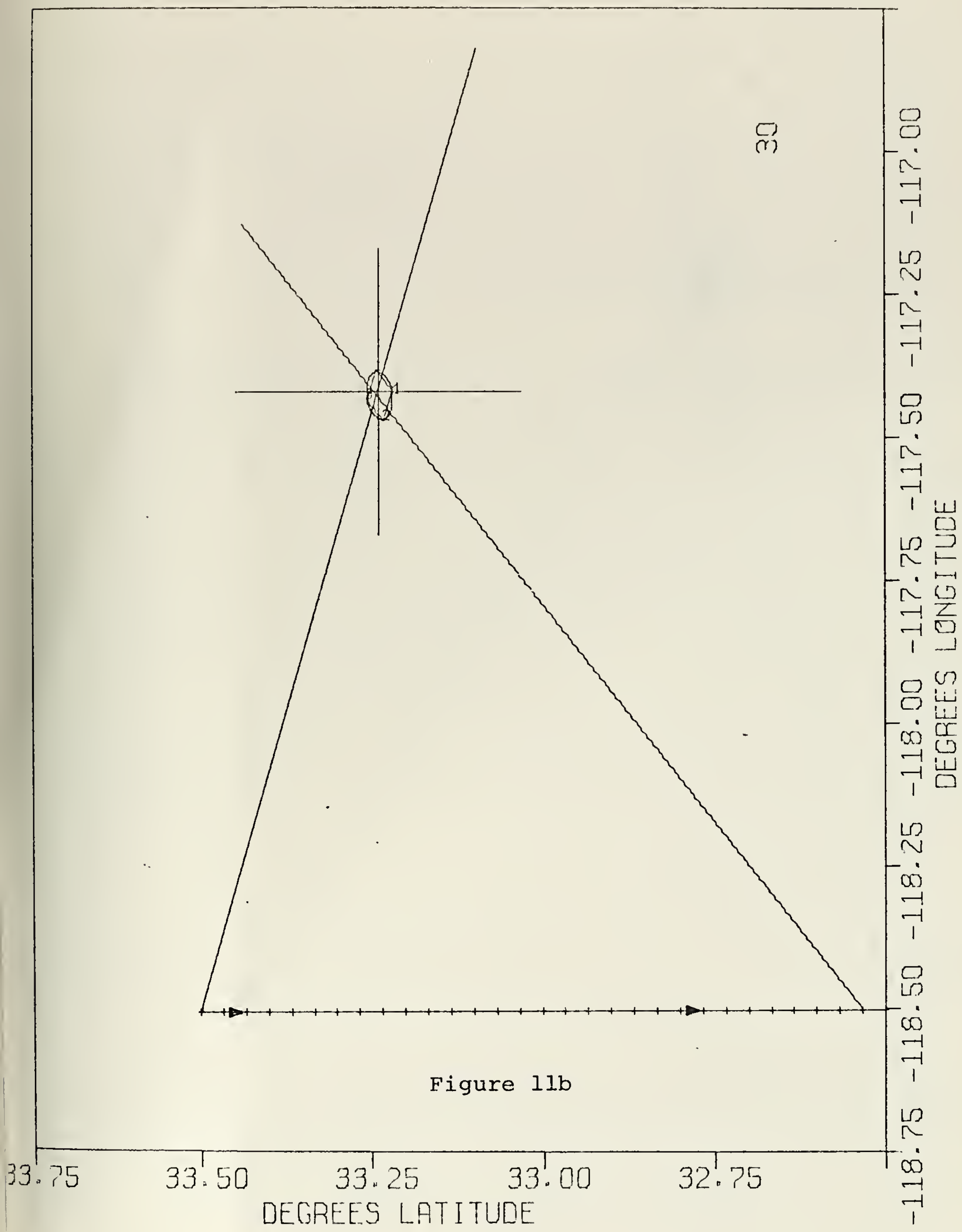

Figure 11b

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

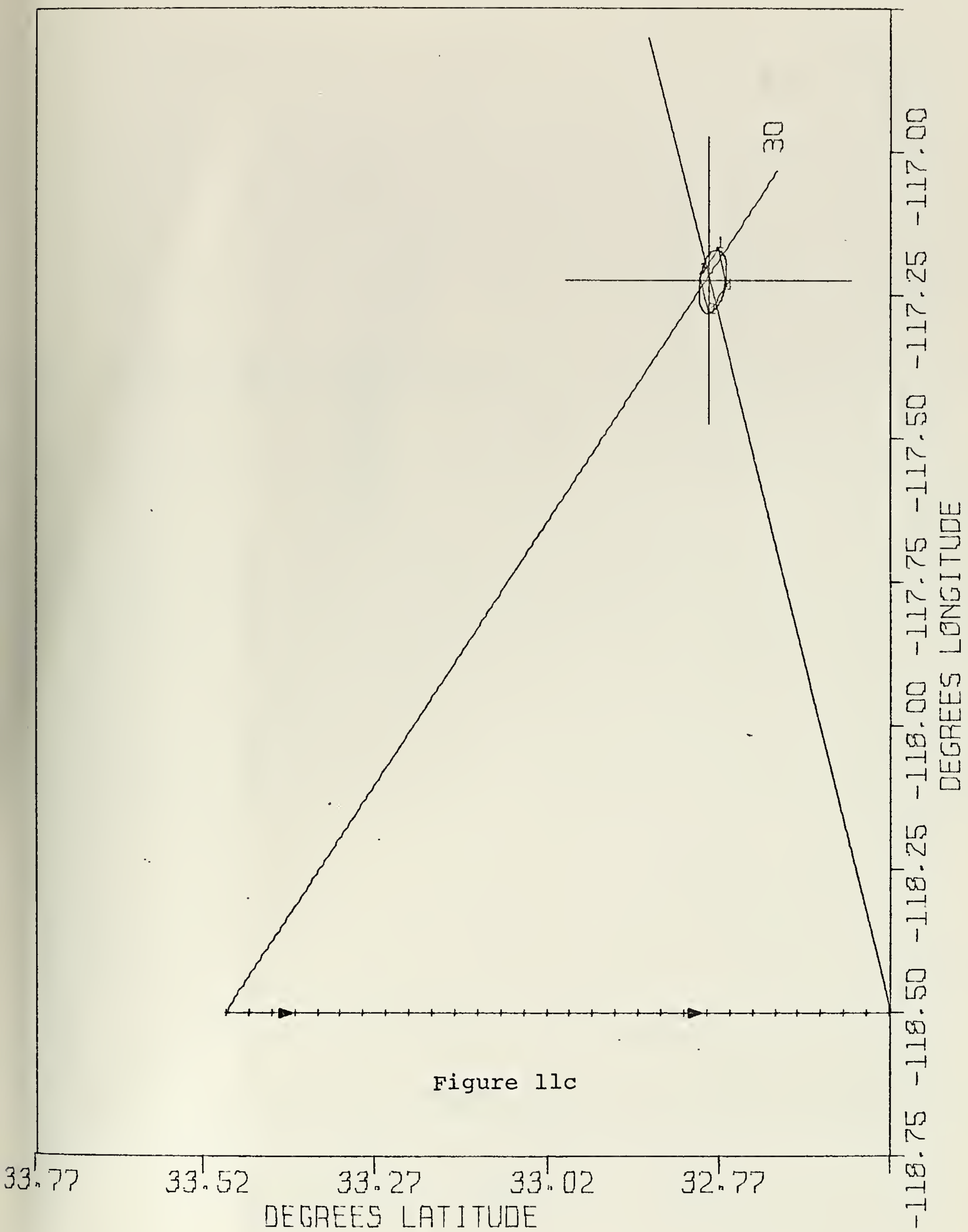

Figure 11c

PLOT OF ERROR COVARIANCES OF EXTENDED KALMANFILTER

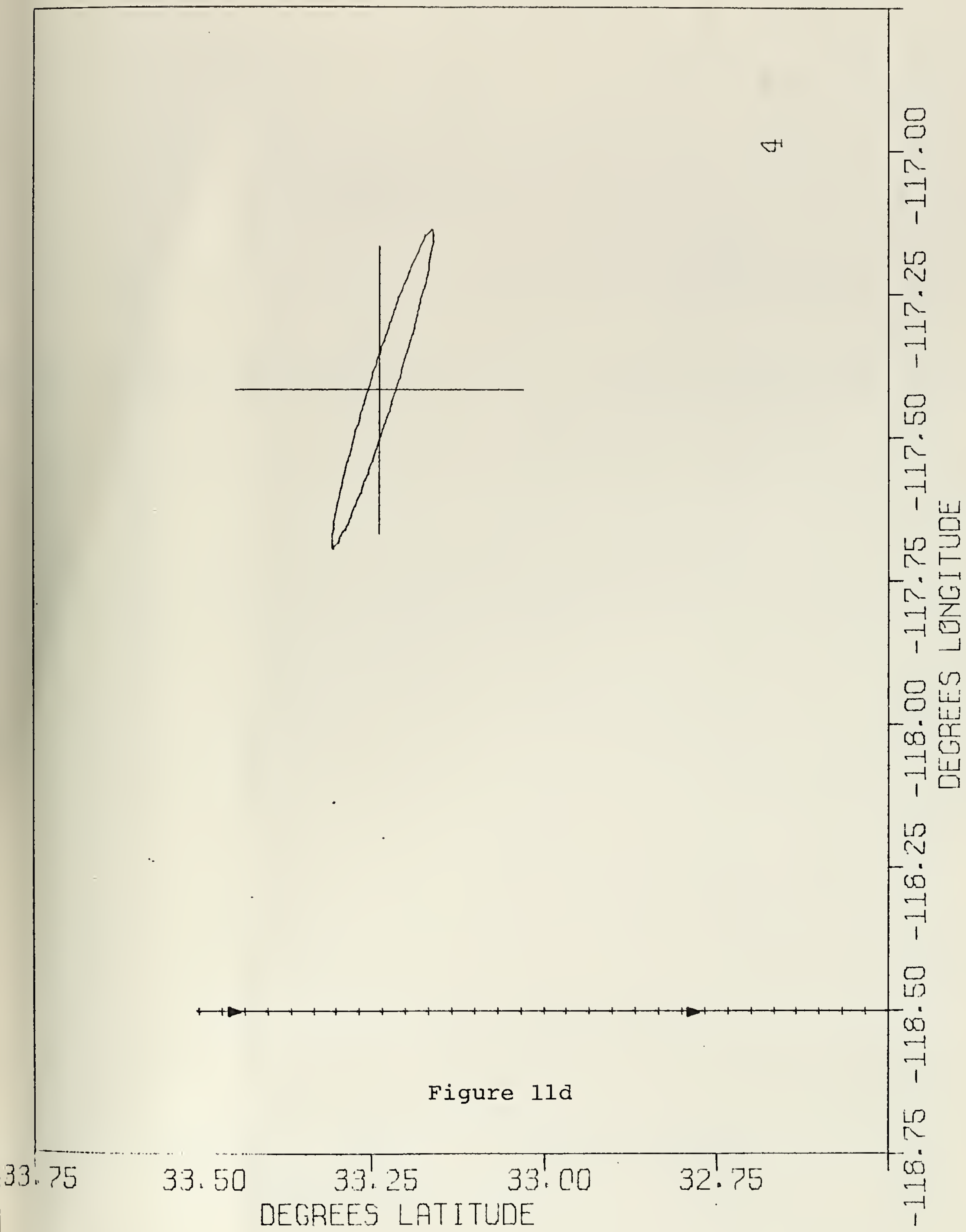

Figure 11d

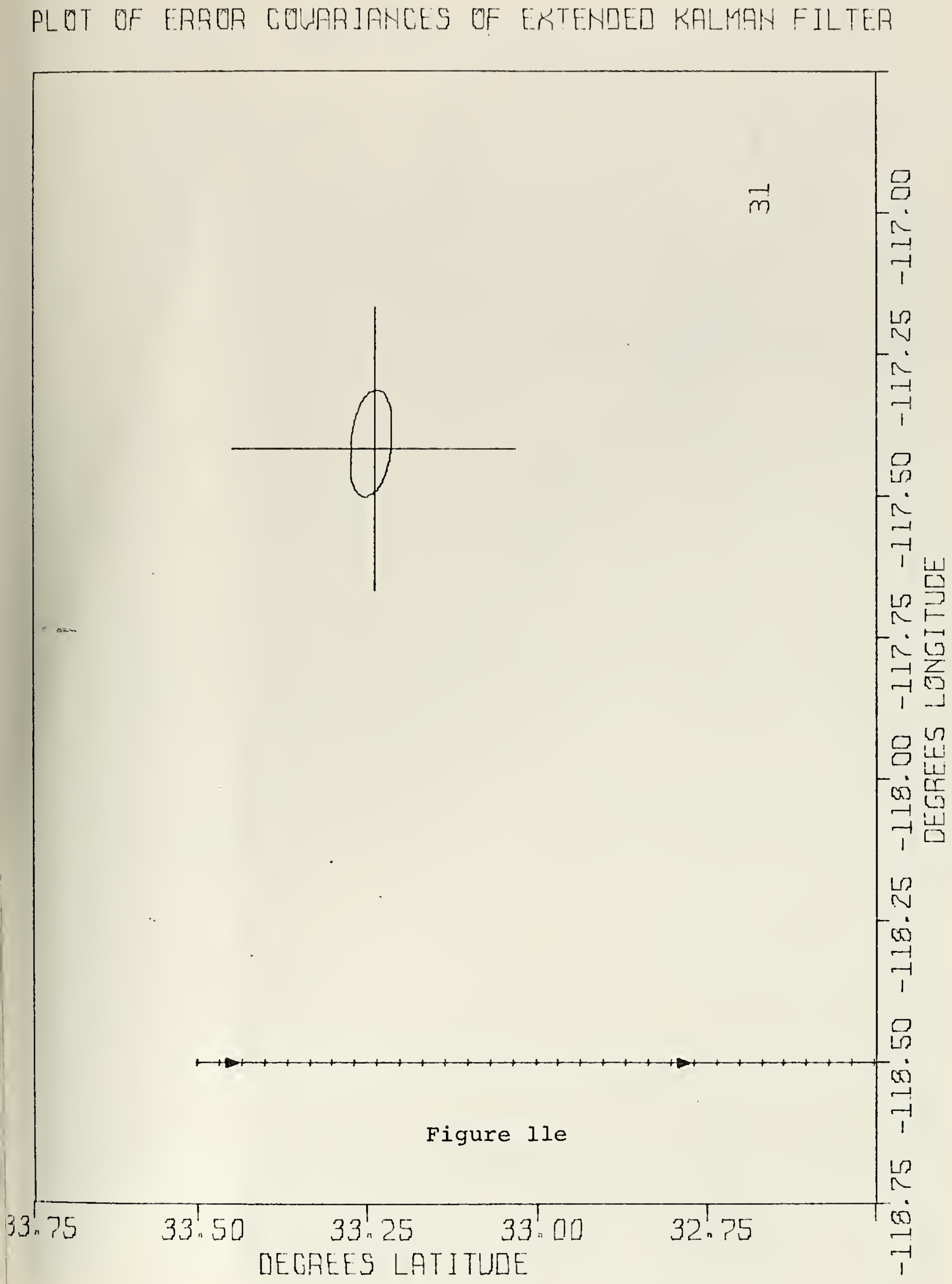
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
31
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 11e

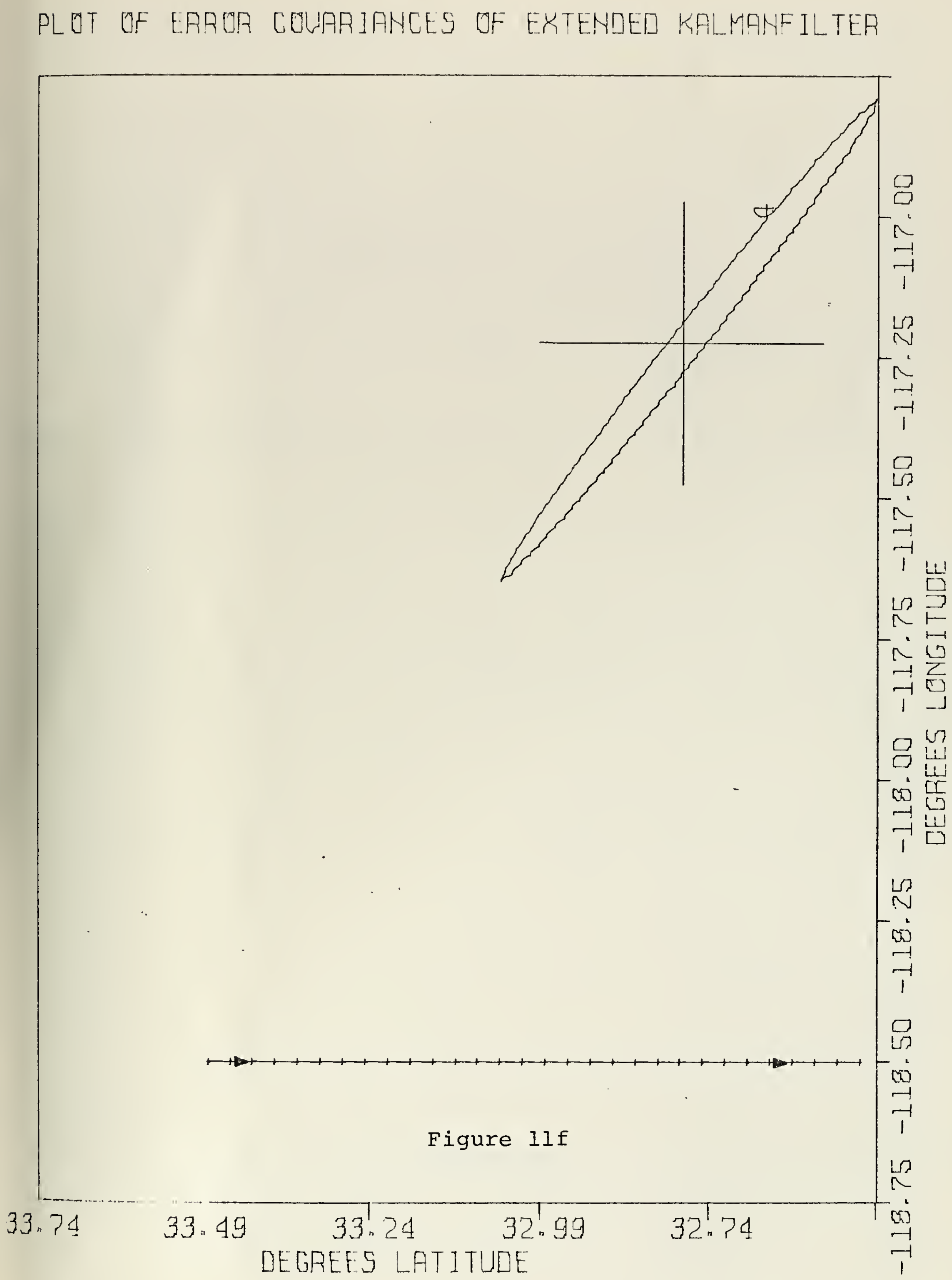
PLOT OF ERROR COVARIANCES OF EXTENDED KALMANFILTER
4
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
-118.75
DEGREES LONGITUDE
33.74
33.49
33.24
32.99
32.74
DEGREES LATITUDE

Figure 11f

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

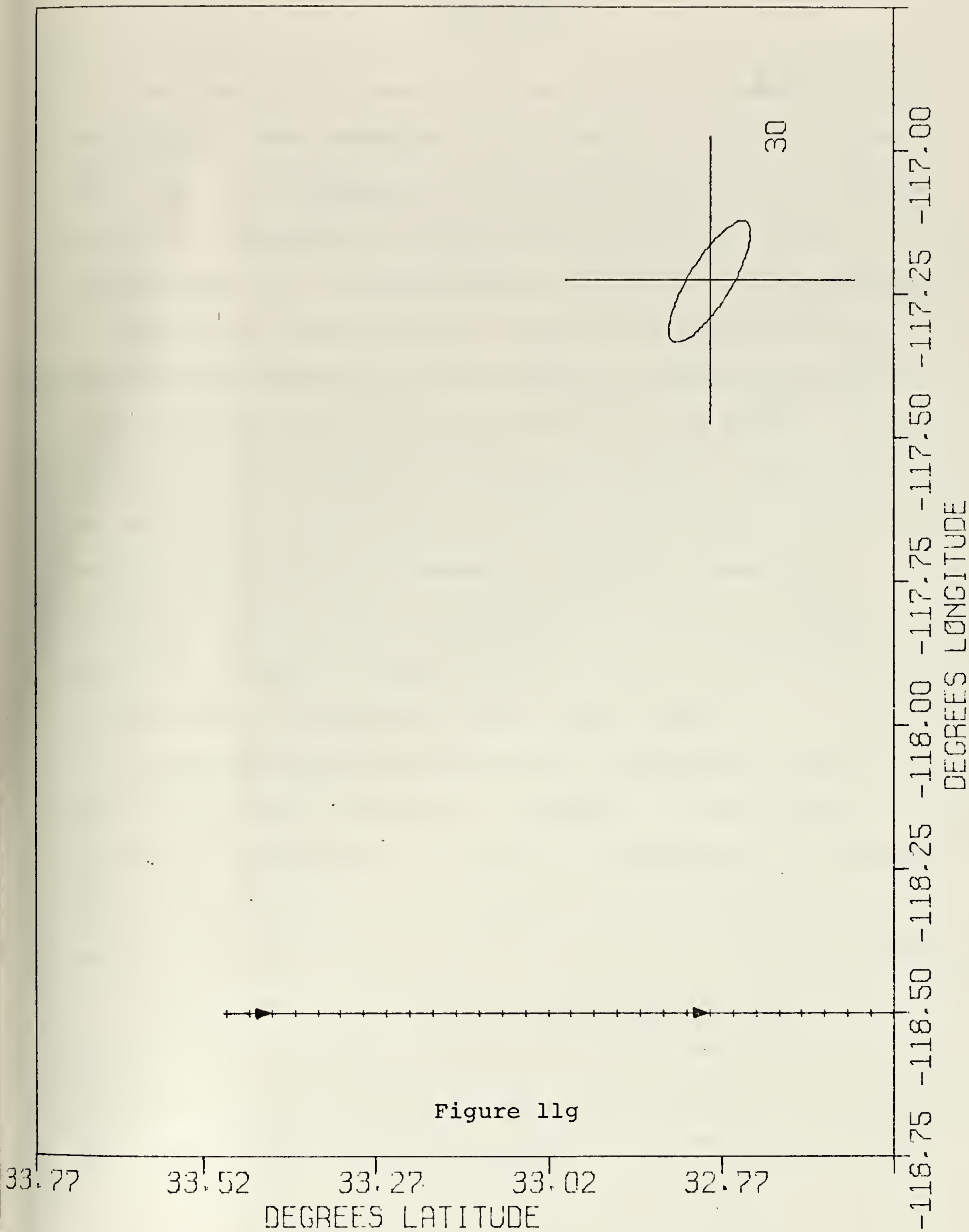

Figure 11g

CONCLUSIONS

The fact that Kalman filtering of digital data works is nothing new, many examples can be found in the literature. This report has shown a particular application of the Kalman theory and presented a program which will work in that application, i.e. the processing of airborne DF information.

There are several areas of this study which need more research and testing. A more complete model for the navigation filter could be developed which would reduce the bias present in the one utilized for this report. Then it should be determined if the bias is harmful or not and if it is worth the resulting increases in computer processing to remove the small error. The response of the two emitter position locating filters should be looked at to determine if there is a more optimal Q for both schemes.

A program for plotting the error ellipses of each target for each filtering scheme was presented. This program provides a capability for displaying graphically the effect of varying the different parameters which are inputs to the subroutines, plus the effect of varying filter response time.

Many current elint systems have a digital computer as a link in their processing chain, but it is used strictly as a device to plot the data and no attempt is made to compute an optimal emitter location solution. By implementing this

Kalman filter program, the effectiveness of the elint system could be greatly enhanced by reducing manual processing time and produce more accurate target position coordinates.

APPENDIX A

DERIVATION OF SCALAR KALMAN FILTER RECURSION EQUATIONS

The Kalman filter equations for all of the linear models in this program can be derived in the same general form described below. The variable names used in each individual subroutine to represent the general terms in the derivation are listed at the end of this section.

The Kalman filter recursion equations from page 10, (7) through (11), are listed below:

$$P(k|k-1) = \phi(k,k-1)P(k-1|k-1)\phi(k,k-1)^T + Q(k) \tag{1A}$$

$$G(k) = P(k|k-1)H(k)^T[H(k)P(k|k-1)H(k)^T + R(k)]^{-1} \tag{2A}$$

$$P(k|k) = P(k|k-1) - G(k)H(k)P(k|k-1) \tag{3A}$$

$$\hat{X}(k|k) = \hat{X}(k|k-1) + G(k)\ [Z(k) - H(k)\hat{X}(k|k-1)] \tag{4A}$$

$$\hat{X}(k|k-1) = \phi(k,k-1)\hat{X}(k-1|k-1) \tag{5A}$$

where in this application $\phi(k+1,k) = \begin{bmatrix} 1 & T(k+1) \\ 0 & 1 \end{bmatrix}$,

$H(k) = [1 \quad 0]$,

the P and Q matrices may be considered to have scalar components given by

$$\begin{bmatrix} P11 & P12 \\ P21 & P22 \end{bmatrix} \text{ and } \begin{bmatrix} Q11 & Q12 \\ Q21 & Q22 \end{bmatrix} \text{ respectively,}$$

and the G matrix is a 2x1 matrix of the form $\begin{bmatrix} G1 \\ G2 \end{bmatrix}$.

Writing (2A) in matrix notation yields

$$\begin{bmatrix} G1 \\ G2 \end{bmatrix} = \begin{bmatrix} P11 & P12 \\ P21 & P22 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \left\{ \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} P11 & P12 \\ P21 & P22 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} + R \right\}^{-1} ; \qquad (6A)$$

and for the observation matrix $H(k) = [1 \quad 0]$, the inverse term becomes a scalar allowing the gain terms to be computed directly as is shown below:

$$\begin{bmatrix} G1 \\ G2 \end{bmatrix} = \begin{bmatrix} P11 \\ P21 \end{bmatrix} \begin{bmatrix} P11 + R \end{bmatrix}^{-1} \qquad (7A)$$

which results in the scalar gain equations

$$G1(k) = \frac{P11(k|k-1)}{P11(k|k-1) + R(k)} \qquad (8A)$$

$$G2(k) = \frac{P21(k|k-1)}{P11(k|k-1) + R(k)} \qquad (9A)$$

let the P matrix be defined by

$$P(k/k-1) = E \left[\Theta(k) - \hat{\theta}(k|k-1)\right] \left[\Theta(k) - \hat{\theta}(k|k-1)\right]^T \qquad (10A)$$

from which it can be seen that since $\tilde{\theta}$ and $\tilde{\theta}$ are statistically independent, where

$\tilde{\theta} = \Theta - \hat{\theta}$,

then $P12 = P21$, and the P matrix is symetric. From (15) it can be seen that the Q matrix is also symetric. Equation (9A) then becomes

$$G2(k) = \frac{P12(k|k-1)}{P11(k|k-1) + R(k)} \qquad (11A)$$

To solve for the prediction covariance terms, (3A) was substituted into (1A) giving

$$\begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix}_{k-1|k} = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} \left\{ \begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix}_{k|k-1} - \begin{bmatrix} G1 \\ G2 \end{bmatrix} \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix}_{k|k-1} \right\} \begin{bmatrix} 1 & 0 \\ T & 1 \end{bmatrix} + \begin{bmatrix} Q11 & Q12 \\ Q12 & Q22 \end{bmatrix} \quad (12A)$$

VARIABLE NAMES USED IN PROGRAM TO REPRESENT VARIABLES IN GENERAL DERIVATION

General Variable	R	P	P	G	X	X	X	E	Z
Subroutine Name									
NAV	RNAV	SP	SPKK	SG					
LATITUDE					SLAD	VELED	SLATD	ELAT	ACLAD
LONGITUDE					SLOD	VELND	SLOND	ELON	ACLOD
GEORGE	RCUT	P	-	G	THTD	TDTD	TPTD	E	THETAD
EXTEND	EXTEND	EP	-	G					
LATITUDE					XTD	XTDDOT	XTDHAT	EX	XTD1
LONGITUDE					YTD	YTDDOT	YTDHAT	EY	YTD1
LINEARIZED MEASURE-MENT		P	-		XTD1 YTDL	- -	TX TX	ER ER	THETA THETA

APPENDIX B

DERIVATION OF SMOOTHING FILTER EQUATIONS

A. FIXED POINT SMOOTHING

The equations used to smooth the estimates of the first DF bearing, THTD1, for a given target are listed on page 15 and are repeated below with $k = 1$.

1. Filter Equation

$$\hat{X}(1|j) = \hat{X}(1|j-1) + W(j)H(j)^{T}R^{-1}(j)\Big[Z(j) - H(j)\phi(j,j-1)X(j-1|j-1)\Big] \qquad (1B)$$

where $j = 2,3,\ldots,$ and the initial condition is $\hat{X}(1|1)$.

2. Gain Equation

$$W(j) = W(j-1)\phi(j,j-1)^{T}\Big[I-S(j)P(j|j)\Big] \qquad (2B)$$

where $W(1) = P(1|1)$ and $S(j) = H(j)^{T}R^{-1}(j)H(j)$

3. Covariance Equation

$$P(1|j) = P(1|j-1) - W(j)\Big[S(j)P(j|j-1)S(j) + S(j)\Big]W(j)^{T} \qquad (3B)$$

where the initial condition is $P(1|1)$. $P(j|j)$ and $P(j|j-1)$ are the error covariance matrices from the optimal filter and predictor respectively. Since $H = [1 \quad 0]$ and $R(j)$ is a scalar, these matrix equations become scalar expressions.

To compute a smoothed estimate of $\hat{X}(1|j)$, it is first necessary to solve (2B) for the values of the gains to be used in (1B).

First solve for S(j)

$$S(j) = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \frac{1}{R} \begin{bmatrix} 1 & 0 \end{bmatrix} = \begin{bmatrix} 1/R & 0 \\ 0 & 0 \end{bmatrix} \qquad (4B)$$

Then noting that

$$\phi(j,j-1) = \begin{bmatrix} 1 & 0 \\ T(j) & 1 \end{bmatrix} \qquad (5B)$$

Equation (2B) becomes

$$\underset{(1/j)}{\begin{bmatrix} W11 & W12 \\ W21 & W22 \end{bmatrix}} = \underset{(1/j-1)}{\begin{bmatrix} W11 & W12 \\ W21 & W22 \end{bmatrix}} - \begin{bmatrix} 1 & 0 \\ T & 1 \end{bmatrix} \left\{ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 1/R & 0 \\ 0 & 0 \end{bmatrix} \underset{(j/j)}{\begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix}} \right\} \qquad (6B)$$

To solve (1B) first note that

$$\hat{Z}(j) = H(j)\phi\hat{X}(j-1|j-1) = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = X_1 + X_2 T \qquad (7B)$$

so therefore let $E(j)=Z(j)-X_1(j)-X_2(j)T(j)$. Then in the notation used in the program

$$\underset{(1/j)}{\begin{bmatrix} THTD1 \\ TDTD1 \end{bmatrix}} = \underset{(1/j-1)}{\begin{bmatrix} THTD1 \\ THTD1 \end{bmatrix}} + \begin{bmatrix} W11 & W12 \\ W21 & W22 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \frac{E(j)}{R} . \qquad (8B)$$

The error covariance matrix for the fixed point smoothing filter is

$$D = \begin{bmatrix} D11 & D12 \\ D21 & D22 \end{bmatrix} \qquad (9B)$$

so (3B) written matrix form is

$$\underset{(1|j)}{\begin{bmatrix} D11 & D12 \\ D21 & D22 \end{bmatrix}} = \underset{(1|j-1)}{\begin{bmatrix} D11 & D12 \\ D21 & D22 \end{bmatrix}} - \begin{bmatrix} W11 & W12 \\ W21 & W22 \end{bmatrix} \begin{bmatrix} 1/R & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix}$$

$$\begin{bmatrix} 1/R & 0 \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} 1/R & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} W11 & W21 \\ W12 & W22 \end{bmatrix} \qquad (10B)$$

B. FIXED INTERVAL SMOOTHING

The fixed interval smoothing equations are listed on page and are repeated below.

1. Filter Equation

$$\hat{X}(k|n) = \hat{X}(k|k) + A(k)\left[\hat{X}(k+1|n) - \hat{X}(k+1|k)\right] \qquad (11B)$$

for k = n-1,n-2,...,0, where $\hat{X}(n|n)$ is the boundary condition for k = n-1.

2. Gain Equation

$$A(k) = P(k|k)\phi(k+1,k)^T P^{-1}(k+1|k) \qquad (12B)$$

3. Covariance Equation

$$P(k|n) = P(k|k) + A(k)\left[P(k+1|n) - P(k+1|k)\right]A(k)^T \qquad (13B)$$

The covariance equation is not used in the computation of the smoothed estimate of $\hat{X}(k|n)$ or filter gain A(k), so it was not utilized in the program.

First the values of the gain matrix A, are computed. Using the notation $PIN=P^{-1}$ (12B) becomes

$$\begin{bmatrix} A11 & A12 \\ A21 & A22 \end{bmatrix} = \begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ T & 1 \end{bmatrix} \begin{bmatrix} PIN11 & PIN12 \\ PIN12 & PIN22 \end{bmatrix} \qquad (14B)$$

where P(k|k) and P(k+1|k) are the covariance terms from the optimal filter equations and the fact that P12=P21 is utilized.

Again letting $E(k) = \hat{X}(k+1|n) - H(k)\phi(k+1|k)\hat{X}(k|k)$, (11B) becomes

$$\hat{X}(k|n) = \hat{X}(k|k) + A(k)E(k) \tag{15B}$$

and (11B) is written in the notation used in the program as

$$\begin{bmatrix} \text{SLAPSM} \\ \text{VELNDSM} \end{bmatrix} = \begin{bmatrix} \text{SLAD} \\ \text{VELND} \end{bmatrix} + \begin{bmatrix} \text{A11} & \text{A12} \\ \text{A21} & \text{A22} \end{bmatrix} \begin{bmatrix} \text{ELAD1} \end{bmatrix} \tag{16B}$$

and

$$\begin{bmatrix} \text{SLODSM} \\ \text{VELEDS} \end{bmatrix} = \begin{bmatrix} \text{SLOD} \\ \text{VELED} \end{bmatrix} + \begin{bmatrix} \text{A11} & \text{A12} \\ \text{A21} & \text{A22} \end{bmatrix} \begin{bmatrix} \text{ELON1} \end{bmatrix}. \tag{17B}$$

APPENDIX C

DERIVATION OF THE VECTOR METHOD POSITION LOCATING ALGORITHM

This algorithm is divided into three basic sections; (A) computation of normal vectors to the bearing plane, (B) computation of bearing vectors, and (C) computation of the target position vector.

A. COMPUTATION OF THE NORMAL VECTOR TO THE BEARING PLANE

The normal vector of the bearing planes are computed as described in Section II,D, using the aircraft latitude and longitude (ϕ,θ), and the DF bearing angle α.

The bearing plane has the equation $dxx + dyy + dzz = 0$. The normal vector, N, can be written in the form

$$N = dxi + dyj + dzk \tag{1C}$$

where i,j,k are the unit base vectors in the x,y,z directions. The components dx, dy, and dz, of normal vector N correspond to the coefficients found from (27). That is

$$dx = -\sin\alpha \sin\theta - \cos\alpha \cos\theta \sin\phi \tag{2C}$$

$$dy = \sin\alpha \cos\theta - \cos\alpha \sin\theta \sin\phi \tag{3C}$$

$$dz = \cos\alpha \cos\phi \tag{4C}$$

B. COMPUTATION OF BEARING VECTOR

Let $SI(x,y,z) = xI + yj + zk$ denote the aircraft position vector. The cross product of SI and N produce the vector

perpendicular to the plane of both SI and N which is the bearing vector D(I), thus

$$D(I) - SI \times N = \begin{vmatrix} 1 & j & k \\ x & y & z \\ dx & dy & dz \end{vmatrix} \qquad (5C)$$

so that $D(I) = A(I)i + B(I)j + C(I)k$, $I=1,2$, where

$$A = y \times DZ - z \times DY \qquad (6C)$$

$$B = z \times DX - x \times DZ \qquad (7C)$$

$$C = x \times DY - y \times DX. \qquad (8C)$$

Then each of the vectors is normalized to determine the length of the unit vector by dividing by D where

$$D = \sqrt{A^2 + B^2 + C^2}\ . \qquad (9C)$$

C. COMPUTATION OF THE TARGET POSITION VECTOR

The two bearing vectors D(1) and D(2) are cross multiplied to find the x,y,z coordinates of the target vector. So

$$X = D(1) \times D(2) = \begin{vmatrix} x & y & z \\ A1 & B1 & C1 \\ A2 & B2 & C2 \end{vmatrix}\ . \qquad (10C)$$

The algorithm for finding the target position vector is therefore

$$X1 = B1 \times C2 - B2 \times C1 \qquad (11C)$$

$$X2 = A2 \times C1 - A1 \times C2 \qquad (12C)$$

$$X3 = A1 \times B2 - A2 \times B1\ . \qquad (13C)$$

This vector is normalized to a unit vector with one unit being the radius of the earth.

To find the latitude and longitude coordinates of the target position the following equations are used

$$TLAD = \tan^{-1}\left(\frac{X3}{\sqrt{X1^2 + X2^2}}\right) \qquad (14\ )$$

$$TLOD = \tan^{-1}\left(\frac{X2}{X1}\right) \qquad (15\ )$$

D. EXAMPLE OF VECTOR METHOD FOR LOCATING TARGET POSITION

A DF bearing of 30 degrees is taken when the aircraft is at latitude 30 degrees north and longitude 45 degrees east. A second DF bearing of 60 degrees is taken from the same emitter when the aircraft is at 31 degrees north and 45 east.

1. First find the normal vector to the bearing plane by substituting the values of ϕ, θ, and α into (2C) through (4C).

$$DX = -\sin 30 \sin 45 - \cos 30 \cos 45 \sin 30 = -.6597$$

$$DY = \sin 30 \cos 45 - \cos 30 \sin 45 \sin 30 = .0473$$

$$DZ = \cos 30 \cos 30 = .750$$

2. Using (21) through (23) find the x,y, and z components of the aircraft position vector.

$$x = \cos 30 \cos 45 = .6123$$

$$y = \cos 30 \sin 45 = .6123$$

$$z = \sin 30 = .500$$

3. Next find the bearing vector, D(I), which is the cross product of the aircraft position vector and the normal to the bearing plane, using (6C) through (8C).

$$A1 = .6123 \times .750 - .50 \times .0473 = .4356$$

$$B1 = .50 \times (-.6597) - .6123 \times .750 = -.7872$$

$$C1 = .6123 \times .0473 - .6123 \times (-.6597) = .4329$$

4. Find the value of D that will normalize D(I) to a unit vector. Using (9C)

$$D = \sqrt{.1897 + .6228 + .187} = 1.0$$

Therefore, the bearing vector is already a unit vector.

5. Similarly the corresponding values for the second bearing are: DX = .7944, DY = .4302, DZ = .42855, x = .6061, y = .6061, and z = .5150.

6. Since the angle of arrival of the second DF bearing is larger than the angle of the first bearing, the second bearing must be crossed into the first to obtain the outward pointing position vector. Therefore from (9C) and (11C) through (13C)

$$X1 = (-.6688) \times .4329 - (-.7892) \times .7422 = .2962$$

$$X2 = .4356 \times .7422 - .0381 \times .4329 = .3068$$

$$X3 = .0381 \times (-.7892) - .4356 \times (-.6031) = .2613$$

$$D = \sqrt{.0877 + .0941 + .0682} = .50$$

7. Find the longitude and latitude coordinates of the target position using (14C) and (15C).

TLOD = ARCTAN(.6136/.5924) = 46.0 degrees

TLAD = ARCTAN(.5224/.8529) = 31.5 degrees

The computer solution to this problem was TLOD = 46.01540 and TLAD = 31.49590.

APPENDIX D

DERIVATION OF EXTENDED KALMAN FILTER EQUATIONS

A. ERROR COVARIANCE EQUATION INITIALIZATION

The ellipse described by the P11 and D11 terms in the angle filtering routine lies in the X'Y' coordinate system which is rotated counter-clockwise (90 - α) degrees from the XY coordinate system used in the Extended Kalman Filter. To determine the values of the axes of the ellipse in the XY coordinate system, the transformation T, described by (51) was utilized.

$$T = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \tag{1D}$$

Let the semi-major axis be $A' = E[X' - \hat{X}']$, and the semi-major axis be $C' = E[Y' - \hat{Y}']$. Define $Z = TX$ where $X^T = [A' \quad C']$, then the error covariance matrix P, in the XY frame is

$$P = E\left[Z\ Z^T\right] = T\ E\left[X\ X^T\right]T^T. \tag{2D}$$

Writing this equation in matrix form yields

$$\begin{bmatrix} P11 & P12 \\ P12 & P21 \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} A' \\ C' \end{bmatrix} \begin{bmatrix} A' & C' \end{bmatrix} \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \tag{3D}$$

Carrying out the indicated matrix multiplications in (3D) produces (52) through (54) which are repeated here.

$$P11(KI) = (A\ \sin\alpha)^2 + (C\ \cos\alpha)^2 \tag{4D}$$

$$P12(KI) = \sin\alpha \cos\alpha \, (A^2 - C^2) \tag{5D}$$

$$P22(KI) = (A \cos\alpha)^2 + (C \sin\alpha)^2 \tag{6D}$$

B. LATITUDE AND LONGITUDE FILTER EQUATIONS

The block diagram for the filter system used in subroutine Extend is shown in Fig. 1. As stated in Section III, part F, the latitude and longitude filters are identical to the corresponding filters used in Subroutine Nav to compute the optimal aircraft position estimates. The recursion equations for these filters are derived in Appendix A with the variable names utilized in this subroutine being listed at the end of Appendix A.

C. LINEARIZED MEASUREMENT EQUATIONS

The extended Kalman filter recursion equations (36) through (40) are similar in form to the basic Kalman filter recursion equations on page , except that the observation matrix is a nonlinear transformation matrix M as defined by (35) where

$$M(k) = \left.\frac{\partial\hat{\theta}}{\partial X}\right|_{\hat{X}} = \begin{bmatrix} \dfrac{\partial\hat{\theta}}{\partial\lambda_T} & \dfrac{\partial\hat{\theta}}{\partial L_T} \end{bmatrix} = \begin{bmatrix} DMX & DMY \end{bmatrix} \tag{7D}$$

Taking partial derivatives of (31) yields

$$DMX = \frac{\partial\hat{\theta}}{\partial\lambda_T} = \frac{(L_T-L)\ \cos L_T}{(L_T-L)^2 + (\lambda_T-\lambda)^2\ \cos^2 L_T} \tag{8D}$$

$$DMY = \frac{\partial\hat{\theta}}{\partial L_T} = \frac{-(\lambda_T-\lambda)\left[(L_T-L)\ \sin L_T + \cos L_T\right]}{(L_T-L)^2 + (\lambda_T-\lambda)^2\ \cos^2 L_T} \tag{9D}$$

These terms are computed numerically and substituted into equations (36) and (37) which are rewritten in matrix form as

$$\begin{bmatrix} GX \\ GY \end{bmatrix} = \begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix} \begin{bmatrix} DMX \\ DMY \end{bmatrix} \left\{ \begin{bmatrix} DMX & DMY \end{bmatrix} \begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix} \begin{bmatrix} DMX \\ DMY \end{bmatrix} + R \right\}^{-1} \qquad (10D)$$

and

$$\begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix}_{k+1|k} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} P11 & P12 \\ P12 & P22 \end{bmatrix}_{k|k} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} Q11 & Q12 \\ Q12 & Q22 \end{bmatrix} \qquad (11D)$$

Equation (38) is then substituted into (10D); however, the fact that the ϕ matrix is the identity matrix considerably simplifies the recursion equations since they are no longer dependent on the sampling interval T(k). Since the gain terms are computed as a function of the nonlinear terms DMX and DMY, it is essential to have the correct units for the error term ER(k). In this case the units of gain are not dimensionless but degrees per radian, so the error term must be given in radians to update the target position estimates in degrees of latitude and longitude.

Equation (40) is substituted into (39) and written in the notation used in the program is

$$XTD1(k) = XTD(k) + GX(k)ER(k) \qquad (12D)$$

and

$$YTD1(k) = YTD(k) + GY(k)ER(k). \qquad (13D)$$

APPENDIX E

MONTE CARLO SIMULATION ERROR ANALYSIS

ESTIMATED AIRCRAFT POSITION ERROR IN DEGREES LATITUDE

	LATITUDE		LONGITUDE	
RUN #	NOISE ADDED TO POSITION	SMOOTHED POSITION ERROR	NOISE ADDED TO POSITION	SMOOTHED POSITION ERROR
1	-0.921E-04	-0.708E-04	0.143E-03	0.117E-03
2	0.775E-05	0.388E-04	0.125E-03	0.103E-03
3	0.748E-04	0.958E-04	-0.378E-04	-0.610E-04
4	-0.403E-04	-0.200E-04	0.236E-03	0.213E-03
5	0.883E-04	0.114E-03	-0.152E-03	-0.182E-03
6	-0.785E-04	-0.548E-04	0.158E-04	-0.125E-04
7	0.348E-04	0.578E-04	-0.670E-04	-0.918E-04
8	0.196E-03	0.226E-03	0.255E-04	-0.775E-05
9	-0.723E-04	-0.503E-04	-0.153E-04	-0.333E-04
10	-0.138E-03	-0.115E-03	0.405E-04	0.775E-05
11	-0.119E-03	-0.886E-04	0.225E-03	0.199E-03
12	-0.580E-04	-0.325E-04	0.725E-04	0.483E-04
13	0.643E-04	0.873E-04	0.485E-04	0.901E-05
14	0.758E-04	0.108E-03	0.625E-04	0.383E-04
15	0.104E-03	0.128E-03	0.455E-04	0.130E-04
16	-0.172E-03	-0.146E-03	-0.998E-04	-0.131E-03
17	-0.948E-04	-0.718E-04	-0.833E-04	-0.105E-03
18	0.158E-03	0.180E-03	-0.132E-03	-0.152E-03
19	0.543E-04	0.765E-04	-0.713E-04	-0.923E-04
20	0.926E-04	0.122E-03	0.124E-03	0.873E-04
21	-0.758E-04	-0.505E-04	0.295E-04	0.926E-05
22	-0.888E-04	-0.703E-04	0.113E-03	0.926E-04
23	-0.588E-04	-0.368E-04	0.107E-03	0.840E-04
24	0.184E-03	0.207E-03	0.338E-04	0.750E-05
25	-0.163E-03	-0.142E-03	0.263E-04	0.875E-05
26	0.393E-04	0.553E-04	0.140E-04	-0.625E-05
27	-0.199E-03	-0.175E-03	0.132E-03	0.110E-03
28	0.264E-03	0.289E-03	-0.108E-03	-0.133E-03
29	0.166E-03	0.190E-03	0.620E-04	0.368E-04
30	-0.208E-03	-0.179E-03	0.238E-04	-0.700E-05
31	0.685E-04	0.926E-04	-0.650E-05	-0.320E-04
32	-0.133E-03	-0.111E-03	-0.153E-03	-0.178E-03
33	-0.100E-05	0.243E-04	0.535E-04	0.295E-04
34	-0.258E-04	-0.125E-05	-0.475E-04	-0.670E-04
35	0.575E-05	0.385E-04	0.112E-03	0.833E-04
36	0.112E-03	0.135E-03	-0.192E-03	-0.229E-03
37	-0.658E-04	-0.375E-04	-0.150E-03	-0.173E-03
38	0.315E-04	0.545E-04	-0.170E-03	-0.201E-03
39	0.245E-04	0.383E-04	-0.465E-04	-0.728E-04
40	0.285E-04	0.448E-04	0.114E-03	0.916E-04
41	0.475E-04	0.713E-04	-0.242E-03	-0.270E-03
42	-0.588E-04	-0.300E-04	0.490E-04	0.253E-04
43	0.145E-03	0.174E-03	-0.307E-11	-0.288E-04
44	0.162E-03	0.189E-03	-0.120E-03	-0.144E-03
45	0.795E-04	0.106E-03	0.107E-03	0.745E-04

AVERAGE ERRORS

	NOISE	MEAN SQUARE NOISE	ERROR	MEAN SQUARE ERROR
ATITUDE	0.814E-05	0.126E-07	0.325E-04	0.137E-07
ONGITUDE	0.552E-05	0.119E-07	-0.205E-04	0.124E-07

MONTE CARLO SIMULATION ERROR ANALYSIS

ESTIMATED EMITTER POSITION ERROR IN NAUTICAL MILES

EXTENDED KALMAN FILTER

```
                  EMITTER # 1                             EMITTER # 2
RUN   DLAT1      DLON1      DRNG1      DLAT2      DLON2      DRNG2

 1  -0.13275   -2.06057    2.06484  -0.26367   -4.77378    4.78105
 2   0.19501   -0.20215    0.28088   0.13458    4.61521    4.61717
 3  -0.41382   -2.82782    2.85794   0.13458    4.61521    4.61717
 4   7.08435   15.22875   16.79591   0.13458    4.61521    4.61717
 5   0.34973    1.51996    1.55968   3.05878   17.13541   17.40627
 6   0.52734    2.15016    2.21388  -0.05127   -6.19852    6.19873
 7   2.55524    5.96270    6.48715  -0.05127   -6.19852    6.19873
 8  -0.41016   -6.43056    6.44363  -0.05127   -6.19852    6.19873
 9   0.48523    1.84157    1.90442   0.76172  -10.95459   10.98104
10   0.36530   -0.51840    0.63417   0.76172  -10.95459   10.98104
11  -0.01373   -0.26877    0.26912   0.76172  -10.95459   10.98104
12  -0.24353   -2.94039    2.95045   3.13110    9.47674    9.98060
13  -0.38086   -4.55913    4.57501   0.79010  -10.04171   10.07274
14   0.46967    1.21750    1.30495   2.88940   17.06227   17.30519
15  -0.51819   -3.60121    3.63830   0.58685    3.54069    3.58900
16   0.15106   -1.57663    1.58385   2.13318    7.10832    7.42150
17   4.17938    9.80282   10.65657  -0.07782   -4.01022    4.01097
18  -0.48706   -2.14326    2.19791  -0.07782   -4.01022    4.01097
19   2.39960    4.55683    5.15003   1.30096  -14.17046   14.23006
20   1.50421    5.11581    5.33237   0.28839   -9.11035    9.11491
21  -0.06042   -2.97637    2.97699   3.81042  -19.66084   20.02667
22   1.65253    3.94042    4.27291   0.65552   -9.76153    9.78352
23  12.78076   21.09802   24.66727   0.47241    0.25247    0.53564
24   0.21240   -0.97324    0.99615   1.27991    1.17305    1.73615
25   1.19476    3.26888    3.48038   0.67291   -7.58709    7.61687
26  -0.17303   -4.62192    4.62516   0.67291   -7.58709    7.61687
27   5.29816    9.67111   11.02728  -0.33142   -0.94059    0.99727
28  -0.15198   -7.01022    7.01186   0.08972    3.94325    3.94427
29   0.15839   -1.37141    1.38053  -0.05310   -8.21902    8.21919
30   1.51886    5.09590    5.31744  -0.05310   -8.21902    8.21919
31   0.22797    2.07282    2.08532   1.58752  -12.84886   12.94656
32   5.62866    8.69098   10.35447   0.97229    5.07089    5.16326
33   0.51544    0.75654    0.91544   0.44403   -8.21594    8.22793
34   3.34991    8.26371    8.91688  -0.39551   -5.82290    5.83631
35  -0.09430   -2.87224    2.87378  -0.42114   -4.47744    4.49720
36   3.70972    8.64734    9.40949  -0.42114   -4.47744    4.49720
37   1.31470    3.19997    3.45951   0.28290   -5.10475    5.11258
38  -0.38177   -3.53918    3.55971   0.02014   -6.37016    6.37020
39   2.58820    5.81645    6.36630   0.33600   -8.64621    8.65274
40  -0.57129   -6.08063    6.10740   1.60767  -14.08425   14.17571
41  -0.13458   -1.26881    1.27592   2.94250   13.34225   13.66287
42   4.53186    7.77977    9.00348   3.24005   10.32419   10.82067
43   4.18488    9.18335   10.09193  -0.04852   -6.79120    6.79137
44  -0.40009  -10.54251   10.55010   2.35657    8.65006    8.96532
45  -0.07507   -1.51843    1.52029   0.31036   -9.50906    9.51413
46  -0.37354   -5.63268    5.64505   2.11945  -13.57008   13.73460
47  -0.47241   -3.34622    3.37940   0.07599   -2.16906    2.17039
48   2.00592    7.79815    8.05201   0.19043   -7.81723    7.81955
49   0.11353   -0.30629    0.32665   0.19043   -7.81723    7.81955
50  -0.00732   -0.84077    0.84080  -0.10895   -1.01371    1.01955

                  AVERAGE ERROR IN NAUTICAL MILES

       AVERAGE    AVERAGE    AVERAGE    AVERAGE    AVERAGE    AVERAGE
      LATITUDE  LONGITUDE     RANGE    LATITUDE  LONGITUDE     RANGE
RUNS    ERROR      ERROR      ERROR      ERROR      ERROR      ERROR

50     1.53497    4.65418    4.98781    0.87208    7.78420    7.87609
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                MONTE CARLO SIMULATION ERROR ANALYSIS
          ESTIMATED EMITTER POSITION ERROR IN NAUTICAL MILES
                  BEARING ANGLE-OF-ARRIVAL FILTER

                   EMITTER # 1                       EMITTER # 2
RUN    DLAT1      DLON1       DRNG1      DLAT2       DLON2       DRNG2

  1  -0.77362   -0.96022    1.23309   -0.18036    -0.03156     0.18310
  2  -0.81299    0.41349    0.91210   -0.60333     1.63641     1.74409
  3  -0.70770   -1.31169    1.49043    0.12726     1.13456     1.14167
  4   1.20026    2.43424    2.71406   -0.60242     1.38549     1.51079
  5   0.11078   -0.15468    0.19025   -0.24078     2.70863     2.71931
  6  -0.25635   -1.06206    1.09256   -0.80383    -2.49311     2.61949
  7   0.52826    1.71829    1.79766    0.97595    -0.94367     1.35757
  8  -1.23230   -1.55595    1.98483   -0.13092     2.88797     2.89094
  9   0.27466   -0.41732    0.49959   -1.48041    -1.51403     2.11752
 10   0.41016   -1.46790    1.52412   -0.29022     3.01959     3.03351
 11   0.19409   -2.42505    2.43281    0.66650     1.50633     1.64720
 12  -0.81116   -0.92500    1.23028    0.17944    -0.24323     0.30226
 13  -1.43005   -1.22133    1.88061   -0.69214    -0.01770     0.69237
 14   0.14740    0.57736    0.59588   -0.37170     2.27605     2.30620
 15  -0.54565   -2.34542    2.40805   -0.28290    -0.16395     0.32697
 16  -0.04211   -0.28332    0.28643   -0.74707     0.21398     0.77711
 17   1.28174    1.62793    2.07196   -0.36072    -2.23910     2.26797
 18  -1.21674   -0.90279    1.51508    1.39160     3.39214     3.66649
 19  -0.21698   -1.59118    1.60590   -1.61499    -2.44308     2.92862
 20   0.74249    0.19143    0.76677   -1.17279    -0.54650     1.29387
 21  -0.14282   -0.58731    0.60443   -0.93842    -3.95942     4.06910
 22   0.70129   -1.15548    1.35165   -0.60974    -0.51648     0.79908
 23   0.56030   -0.97171    1.12167   -0.95673     0.32944     1.01186
 24  -0.74799    1.89134    2.03388   -0.66742    -1.18921     1.36370
 25  -0.08514    0.82162    0.82602   -0.36896    -2.34686     2.37569
 26  -0.91919   -1.17998    1.49575    0.76721     0.91673     1.19541
 27   0.37811    0.20215    0.42876    1.17462    -1.32930     1.77391
 28  -0.92468   -1.51690    1.77652    0.57404     2.32223     2.39213
 29  -0.17303   -0.72744    0.74774   -0.45593    -2.55084     2.59126
 30   0.88531    1.73743    1.94999    0.95123     5.42342     5.50620
 31  -0.08331    0.60492    0.61063   -1.28357    -2.41537     2.73524
 32   1.21307   -1.48704    1.91907   -0.70404     1.98664     2.10770
 33   0.51270   -0.83158    0.97692   -0.38635    -1.90274     1.94156
 34   0.58319    1.59501    1.69828    0.63263    -1.83654     1.94245
 35  -0.76630   -0.14625    0.78013   -1.66718     2.10517     2.68537
 36   0.56854    1.87450    1.95882    0.11444     4.54440     4.54584
 37   0.43396   -2.07665    2.12150   -0.75531    -2.24449     2.36817
 38  -0.95398   -0.95486    1.34975   -0.61249    -1.45322     1.57702
 39   0.62256   -1.19377    1.34635    0.05219    -2.86488     2.86536
 40  -1.44653   -1.89823    2.38658   -1.62140    -2.77405     3.21315
 41  -0.29388   -0.91657    0.96254    0.19501     2.32531     2.33347
 42   0.32593    1.00846    1.05982   -0.05127     1.33546     1.33644
 43   1.08032    0.27030    1.11362   -1.89514    -0.38101     1.93306
 44  -1.64886   -2.81710    3.26417   -0.34149     2.46309     2.48665
 45  -1.29272    0.55285    1.40598   -1.14624    -1.53096     1.91252
 46  -0.74982   -2.17236    2.29813    0.02655    -1.00448     1.00483
 47  -1.05377   -0.67843    1.25328   -0.94391    -0.78357     1.22676
 48   1.37787   -0.28638    1.40732   -0.77545    -3.45987     3.54571
 49  -0.39276   -0.20368    0.44243    0.67017     3.63768     3.69889
 50  -0.39276    0.50614    0.64066   -0.18494     0.78973     0.81109

                 AVERAGE ERROR IN NAUTICAL MILES

        AVERAGE    AVERAGE    AVERAGE    AVERAGE    AVERAGE    AVERAGE
       LATITUDE  LONGITUDE     RANGE    LATITUDE  LONGITUDE     RANGE
RUNS     ERROR      ERROR      ERROR      ERROR      ERROR      ERROR

50      0.68492    1.12906    1.39129    0.68879    1.87039    2.09753
```

```
          LISTING OF EMITTER TARGET DATA

 K   TIMET    FREQ     PRF     PW      BRNGD       THETAD

 1   100.0   1197.0   150.0   3.50   105.98349   106.81114
 2   106.0   1212.0   250.0   3.00   123.17577   124.30956
 3   112.0   1197.0   150.0   3.50   104.01610   104.36736
 4   118.0   1212.0   250.0   3.00   121.91071   122.41992
 5   124.0   1197.0   150.0   3.50   102.01436   102.41859
 6   130.0   1212.0   250.0   3.00   120.60915   121.18193
 7   136.0   1197.0   150.0   3.50    99.98351   100.68506
 8   142.0   1212.0   250.0   3.00   119.27164   118.74664
 9   148.0   1197.0   150.0   3.50    97.92696    96.78751
10   154.0   1212.0   250.0   3.00   117.89893   118.73015
11   160.0   1197.0   150.0   3.50    95.84862    94.37448
12   166.0   1212.0   250.0   3.00   116.49051   116.33717
13   172.0   1197.0   150.0   3.50    93.75478    94.24924
14   178.0   1212.0   250.0   3.00   115.04587   116.48721
15   184.0   1197.0   150.0   3.50    91.65182    92.49257
16   190.0   1212.0   250.0   3.00   113.56721   113.94238
17   196.0   1197.0   150.0   3.50    89.54355    90.58488
18   202.0   1212.0   250.0   3.00   112.05394   112.42679
19   208.0   1197.0   150.0   3.50    87.43718    85.53748
20   214.0   1212.0   250.0   3.00   110.50731   109.75629
21   220.0   1197.0   150.0   3.50    85.33707    87.01108
22   226.0   1212.0   250.0   3.00   108.92969   108.96266
23   232.0   1197.0   150.0   3.50    83.24927    83.44542
24   238.0   1212.0   250.0   3.00   107.32155   108.41565
25   244.0   1197.0   150.0   3.50    81.18033    81.18315
26   250.0   1212.0   250.0   3.00   105.68427   105.95073
27   256.0   1197.0   150.0   3.50    79.13434    79.59174
28   262.0   1212.0   250.0   3.00   104.02003   104.99403
29   268.0   1197.0   150.0   3.50    77.11496    77.19061
30   274.0   1212.0   250.0   3.00   102.33228   103.68779
31   280.0   1197.0   150.0   3.50    75.12862    73.77927
32   286.0   1212.0   250.0   3.00   100.62157   100.01122
33   292.0   1197.0   150.0   3.50    73.17722    72.55504
34   298.0   1212.0   250.0   3.00    98.89243    97.91229
35   304.0   1197.0   150.0   3.50    71.26514    72.24512
36   310.0   1212.0   250.0   3.00    97.14586    96.42537
37   316.0   1197.0   150.0   3.50    69.39635    68.22856
38   322.0   1212.0   250.0   3.00    95.38602    94.80276
39   328.0   1197.0   150.0   3.50    67.57230    67.65929
40   334.0   1212.0   250.0   3.00    93.61652    93.63611
41   340.0   1197.0   150.0   3.50    65.79401    66.59315
42   346.0   1212.0   250.0   3.00    91.84023    89.98112
43   352.0   1197.0   150.0   3.50    64.06415    63.11497
44   358.0   1212.0   250.0   3.00    90.05968    91.48303
45   364.0   1197.0   150.0   3.50    62.38416    60.46066
46   370.0   1212.0   250.0   3.00    88.27945    87.50397
47   376.0   1197.0   150.0   3.50    60.75365    61.14169
48   382.0   1212.0   250.0   3.00    86.50214    87.24391
49   388.0   1197.0   150.0   3.50    59.17412    57.07373
50   394.0   1212.0   250.0   3.00    84.73131    85.86865
51   400.0   1197.0   150.0   3.50    57.64409    56.69685
52   406.0   1212.0   250.0   3.00    82.97147    84.63478
53   412.0   1197.0   150.0   3.50    56.16422    57.10556
54   418.0   1212.0   250.0   3.00    81.22481    81.01143
55   424.0   1197.0   150.0   3.50    54.73453    55.17111
56   430.0   1212.0   250.0   3.00    79.49355    80.80753
57   436.0   1197.0   150.0   3.50    53.35355    54.66557
58   442.0   1212.0   250.0   3.00    77.78148    77.29852
59   448.0   1197.0   150.0   3.50    52.01973    52.38834
60   454.0   1212.0   250.0   3.00    76.09212    76.34935
61   460.0   1197.0   150.0   3.50    50.73331    52.29285
```

AIRCRAFT NAVIGATION COMPUTER DATA

	ACTUAL LATITUDE	NOISY LATITUDE	SMOOTHED LATITUDE	ACTUAL LONGITUDE	NOISY LONGITUDE	SMOOTHED LONGITUDE
1	33.5000	33.5007	33.5007	-118.5000	-118.5012	-118.5011
2	33.4833	33.4841	33.4841	-118.5000	-118.5003	-118.5003
3	33.4667	33.4679	33.4676	-118.5000	-118.5019	-118.5008
4	33.4500	33.4505	33.4504	-118.5000	-118.4985	-118.4999
5	33.4333	33.4332	33.4333	-118.5000	-118.5007	-118.4999
6	33.4167	33.4167	33.4166	-118.5000	-118.4997	-118.4998
7	33.4000	33.3999	33.4001	-118.5000	-118.4992	-118.4997
8	33.3833	33.3836	33.3834	-118.5000	-118.5006	-118.5001
9	33.3667	33.3667	33.3666	-118.5000	-118.5006	-118.5003
10	33.3500	33.3498	33.3495	-118.5000	-118.4994	-118.5000
11	33.3333	33.3322	33.3328	-118.5000	-118.5007	-118.4999
12	33.3167	33.3166	33.3162	-118.5000	-118.4985	-118.4996
13	33.3000	33.2995	33.2999	-118.5000	-118.5010	-118.5001
14	33.2833	33.2834	33.2835	-118.5000	-118.5002	-118.5004
15	33.2667	33.2674	33.2662	-118.5000	-118.5005	-118.5006
16	33.2500	33.2480	33.2491	-118.5000	-118.5011	-118.5007
17	33.2333	33.2327	33.2322	-118.5000	-118.5001	-118.5001
18	33.2167	33.2155	33.2158	-118.5000	-118.4986	-118.4995
19	33.2000	33.1997	33.1996	-118.5000	-118.5004	-118.4995
20	33.1833	33.1831	33.1833	-118.5000	-118.4985	-118.4994
21	33.1667	33.1673	33.1665	-118.5000	-118.5005	-118.5000
22	33.1500	33.1494	33.1497	-118.5000	-118.5007	-118.5005
23	33.1333	33.1328	33.1332	-118.5000	-118.5011	-118.5006
24	33.1167	33.1172	33.1164	-118.5000	-118.4991	-118.5000
25	33.1000	33.0992	33.0997	-118.5000	-118.5005	-118.5000
26	33.0833	33.0832	33.0828	-118.5000	-118.4996	-118.5000
27	33.0667	33.0660	33.0659	-118.5000	-118.5010	-118.5002
28	33.0500	33.0490	33.0493	-118.5000	-118.4995	-118.5000
29	33.0333	33.0329	33.0327	-118.5000	-118.5000	-118.4998
30	33.0167	33.0162	33.0159	-118.5000	-118.4995	-118.4997
31	33.0000	32.9988	32.9993	-118.5000	-118.5000	-118.4997
32	32.9833	32.9831	32.9826	-118.5000	-118.4996	-118.4996
33	32.9667	32.9655	32.9660	-118.5000	-118.4992	-118.4995
34	32.9500	32.9501	32.9491	-118.5000	-118.4997	-118.4998
35	32.9333	32.9315	32.9331	-118.5000	-118.5008	-118.5005
36	32.9167	32.9183	32.9167	-118.5000	-118.5013	-118.5009
37	32.9000	32.8998	32.9005	-118.5000	-118.5005	-118.5005
38	32.8833	32.8841	32.8846	-118.5000	-118.4993	-118.4997
39	32.8667	32.8688	32.8681	-118.5000	-118.4990	-118.4994
40	32.8500	32.8509	32.8510	-118.5000	-118.5003	-118.5000
41	32.8333	32.8338	32.8334	-118.5000	-118.5013	-118.5007
42	32.8167	32.8158	32.8162	-118.5000	-118.5008	-118.5007
43	32.8000	32.7994	32.7998	-118.5000	-118.4998	-118.5002
44	32.7833	32.7833	32.7839	-118.5000	-118.4998	-118.5000
45	32.7667	32.7688	32.7668	-118.5000	-118.5001	-118.5002
46	32.7500	32.7488	32.7496	-118.5000	-118.5016	-118.5008
47	32.7333	32.7322	32.7332	-118.5000	-118.5006	-118.5007
48	32.7167	32.7177	32.7168	-118.5000	-118.5001	-118.5002
49	32.7000	32.7002	32.6998	-118.5000	-118.4993	-118.4997
50	32.6833	32.6824	32.6828	-118.5000	-118.5002	-118.4998
51	32.6667	32.6661	32.6662	-118.5000	-118.4997	-118.4998
52	32.6500	32.6497	32.6502	-118.5000	-118.5001	-118.4999
53	32.6333	32.6346	32.6338	-118.5000	-118.4998	-118.4999
54	32.6167	32.6171	32.6172	-118.5000	-118.4998	-118.4998
55	32.6000	32.6000	32.6005	-118.5000	-118.4996	-118.4998
56	32.5833	32.5843	32.5835	-118.5000	-118.5000	-118.5000
57	32.5667	32.5660	32.5665	-118.5000	-118.5007	-118.5002
58	32.5500	32.5497	32.5496	-118.5000	-118.4997	-118.5000
59	32.5333	32.5330	32.5330	-118.5000	-118.4996	-118.4999
60	32.5167	32.5165	32.5164	-118.5000	-118.5004	-118.5002
61	32.5000	32.4999	32.4999	-118.5000	-118.5004	-118.5004

```
                 NAVIGATION DATA FILTER PARAMETERS

  K     SG1        SG2         SP11        SP12        SP22          T

  1  0.0        0.0        1.00000    0.0        1.00000       0.0
  2  0.99999    0.16216   37.00000    6.00000    1.00004       6.00
  3  0.99957    0.16646    0.97585    0.16251    0.02711       6.00
  4  0.89002    0.11174    0.00337    0.00042    0.00009       6.00
  5  0.86395    0.10864    0.00265    0.00033    0.00008       6.00
  6  0.86253    0.10906    0.00261    0.00033    0.00008       6.00
  7  0.86251    0.10903    0.00261    0.00033    0.00008       6.00
  8  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
  9  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 10  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 11  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 12  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 13  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 14  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 15  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 16  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 17  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 18  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 19  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 20  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 21  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 22  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 23  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 24  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 25  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 26  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 27  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 28  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 29  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 30  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 31  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 32  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 33  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 34  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 35  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 36  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 37  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 38  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 39  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 40  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 41  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 42  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 43  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 44  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 45  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 46  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 47  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 48  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 49  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 50  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 51  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 52  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 53  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 54  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 55  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 56  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 57  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 58  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 59  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 60  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
 61  0.86246    0.10901    0.00261    0.00033    0.00008       6.00
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            NAVIGATION DATA FILTER PARAMETERS

 K   VELND      ELAT         SLATD    VELED     ELON       SLOND

 1 -0.00225  0.0         33.49908  0.00003  0.0      -118.50040
 2 -0.00225  0.0         33.48558  0.00003  0.00003 -118.50020
 3 -0.00316 -0.00546     33.47208 -0.00001 -0.00023 -118.49998
 4 -0.00290  0.00235     33.44765  0.00000  0.00011 -118.50024
 5 -0.00282  0.00075     33.43234 -0.00012 -0.00132 -118.50011
 6 -0.00288 -0.00063     33.41608  0.00012  0.00239 -118.50192
 7 -0.00273  0.00140     33.39821 -0.00010 -0.00224 -118.49911
 8 -0.00256  0.00162     33.38303 -0.00016 -0.00080 -118.50165
 9 -0.00284 -0.00266     33.36908  0.00015  0.00310 -118.50328
10 -0.00279  0.00052     33.34970  0.00010 -0.00029 -118.49971
11 -0.00284 -0.00050     33.33340  0.00014  0.00061 -118.49936
12 -0.00270  0.00134     33.31590 -0.00008 -0.00213 -118.49799
13 -0.00279 -0.00089     33.30086 -0.00005  0.00014 -118.50029
14 -0.00273  0.00055     33.28333  0.00006  0.00114 -118.50047
15 -0.00291 -0.00160     33.26740 -0.00012 -0.00185 -118.49911
16 -0.00278  0.00113     33.24855  0.00003  0.00139 -118.50140
17 -0.00275  0.00032     33.23280  0.00014  0.00130 -118.50003
18 -0.00278 -0.00029     33.21657 -0.00006 -0.00195 -118.49805
19 -0.00281 -0.00031     33.19962 -0.00001  0.00046 -118.50008
20 -0.00256  0.00233     33.18245 -0.00010 -0.00103 -118.49973
21 -0.00298 -0.00383     33.16908 -0.00002  0.00068 -118.50121
22 -0.00276  0.00197     33.14790  0.00001  0.00036 -118.50075
23 -0.00260  0.00153     33.13301  0.00009  0.00082 -118.50034
24 -0.00277 -0.00163     33.11874 -0.00004 -0.00128 -118.49910
25 -0.00294 -0.00154     33.10068  0.00001  0.00049 -118.50046
26 -0.00262  0.00294     33.08167 -0.00008 -0.00093 -118.49998
27 -0.00280 -0.00165     33.06847  0.00002  0.00095 -118.50125
28 -0.00278  0.00017     33.05022  0.00004  0.00031 -118.50031
29 -0.00280 -0.00018     33.03365  0.00003 -0.00012 -118.49976
30 -0.00274  0.00058     33.01665 -0.00011 -0.00142 -118.49968
31 -0.00275 -0.00006     33.00069 -0.00005  0.00049 -118.50154
32 -0.00282 -0.00072     32.98415  0.00000  0.00044 -118.50137
33 -0.00279  0.00035     32.96657  0.00008  0.00088 -118.50098
34 -0.00277  0.00015     32.95013  0.00014  0.00074 -118.49971
35 -0.00274  0.00024     32.93364 -0.00002 -0.00152 -118.49825
36 -0.00272  0.00024     32.91737  0.00001  0.00033 -118.49969
37 -0.00295 -0.00212     32.90126 -0.00005 -0.00065 -118.49934
38 -0.00280  0.00133     32.88174  0.00002  0.00073 -118.50020
39 -0.00260  0.00186     32.86606 -0.00018 -0.00223 -118.49940
40 -0.00280 -0.00186     32.85205  0.00008  0.00256 -118.50243
41 -0.00277  0.00031     32.83360  0.00007  0.00003 -118.49973
42 -0.00274  0.00024     32.81725  0.00005 -0.00012 -118.49927
43 -0.00277 -0.00027     32.80098 -0.00008 -0.00135 -118.49907
44 -0.00285 -0.00067     32.78409 -0.00002  0.00058 -118.50072
45 -0.00299 -0.00130     32.76642 -0.00000  0.00014 -118.50031
46 -0.00265  0.00305     32.74736  0.00005  0.00051 -118.50018
47 -0.00270 -0.00040     32.73405 -0.00002 -0.00063 -118.49947
48 -0.00282 -0.00116     32.71751  0.00011  0.00141 -118.50011
49 -0.00277  0.00047     32.69955 -0.00007 -0.00178 -118.49820
50 -0.00290 -0.00119     32.68330 -0.00000  0.00059 -118.50012
51 -0.00271  0.00172     32.66484  0.00004  0.00044 -118.49962
52 -0.00266  0.00050     32.65002 -0.00003 -0.00071 -118.49901
53 -0.00287 -0.00189     32.63449 -0.00016 -0.00139 -118.49980
54 -0.00270  0.00150     32.61566  0.00008  0.00233 -118.50192
55 -0.00295 -0.00229     32.60072  0.00005 -0.00023 -118.49940
56 -0.00260  0.00323     32.58102 -0.00003 -0.00081 -118.49931
57 -0.00283 -0.00212     32.56819 -0.00011 -0.00089 -118.50020
58 -0.00285 -0.00015     32.54936 -0.00001  0.00090 -118.50162
59 -0.00263  0.00200     32.53214  0.00006  0.00075 -118.50089
60 -0.00278 -0.00134     32.51805 -0.00007 -0.00127 -118.49986
61 -0.00268  0.00092     32.50023  0.00007  0.00133 -118.50134
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          KALMAN FILTER PARAMETERS FOR ANGLE FILTER

I   J   K        P11(K)          P12(K)        G1(K)      G2(K)

1   0   1     10000.0000          0.0         0.9999     0.0
1   2   3   1440001.0000     120000.0000      1.0000     0.0833
1   3   5         6.8125          0.3202      0.8720     0.0410
1   4   7         2.7990          0.1196      0.7368     0.0315
1   5   9         1.9142          0.0666      0.6569     0.0229
1   6  11         1.4289          0.0415      0.5883     0.0171
1   7  13         1.1400          0.0289      0.5327     0.0135
1   8  15         0.9634          0.0224      0.4907     0.0114
1   9  17         0.8548          0.0189      0.4608     0.0102
1  10  19         0.7893          0.0172      0.4411     0.0096
1  11  21         0.7517          0.0163      0.4291     0.0093
1  12  23         0.7317          0.0159      0.4225     0.0092
1  13  25         0.7221          0.0158      0.4193     0.0092
1  14  27         0.7181          0.0157      0.4179     0.0092
1  15  29         0.7167          0.0157      0.4175     0.0092
1  16  31         0.7164          0.0157      0.4174     0.0092
1  17  33         0.7163          0.0157      0.4174     0.0092
1  18  35         0.7162          0.0157      0.4173     0.0092
1  19  37         0.7161          0.0157      0.4173     0.0092
1  20  39         0.7160          0.0157      0.4172     0.0092
1  21  41         0.7159          0.0157      0.4172     0.0092
1  22  43         0.7158          0.0157      0.4172     0.0092
1  23  45         0.7157          0.0157      0.4172     0.0092
1  24  47         0.7157          0.0157      0.4172     0.0092
1  25  49         0.7157          0.0157      0.4171     0.0092
1  26  51         0.7157          0.0157      0.4171     0.0092
1  27  53         0.7157          0.0157      0.4171     0.0092
1  28  55         0.7157          0.0157      0.4171     0.0092
1  29  57         0.7157          0.0157      0.4171     0.0092
1  30  59         0.7157          0.0157      0.4171     0.0092
1  31  61         0.7157          0.0157      0.4171     0.0092
2   0   2     10000.0000          0.0         0.9999     0.0
2   2   4   1440001.0000     120000.0000      1.0000     0.0833
2   3   6         6.8125          0.3202      0.8720     0.0410
2   4   8         2.7990          0.1196      0.7368     0.0315
2   5  10         1.9142          0.0666      0.6569     0.0229
2   6  12         1.4289          0.0415      0.5883     0.0171
2   7  14         1.1400          0.0289      0.5327     0.0135
2   8  16         0.9634          0.0224      0.4907     0.0114
2   9  18         0.8548          0.0189      0.4608     0.0102
2  10  20         0.7893          0.0172      0.4411     0.0096
2  11  22         0.7517          0.0163      0.4291     0.0093
2  12  24         0.7317          0.0159      0.4225     0.0092
2  13  26         0.7221          0.0158      0.4193     0.0092
2  14  28         0.7181          0.0157      0.4179     0.0092
2  15  30         0.7167          0.0157      0.4175     0.0092
2  16  32         0.7164          0.0157      0.4174     0.0092
2  17  34         0.7163          0.0157      0.4174     0.0092
2  18  36         0.7162          0.0157      0.4173     0.0092
2  19  38         0.7161          0.0157      0.4173     0.0092
2  20  40         0.7160          0.0157      0.4172     0.0092
2  21  42         0.7159          0.0157      0.4172     0.0092
2  22  44         0.7158          0.0157      0.4172     0.0092
2  23  46         0.7157          0.0157      0.4172     0.0092
2  24  48         0.7157          0.0157      0.4172     0.0092
2  25  50         0.7157          0.0157      0.4171     0.0092
2  26  52         0.7157          0.0157      0.4171     0.0092
2  27  54         0.7157          0.0157      0.4171     0.0092
2  28  56         0.7157          0.0157      0.4171     0.0092
2  29  58         0.7157          0.0157      0.4171     0.0092
2  30  60         0.7157          0.0157      0.4171     0.0092
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                KALMAN FILTER PARAMETERS FOR ANGLE FILTER


I    J    K     T(K)       THTD(K)      TDTD(K)     E(K)        GATE(K)

1    0    1      0.0      106.6854     0.0930
1    2    3     12.000    104.1513    -0.2112    -3.6504    3600.0022
1    3    5     12.000    102.3046    -0.1789     0.7882       8.3853
1    4    7     12.000    100.2979    -0.1729     0.1896       5.8473
1    5    9     12.000     98.7523    -0.1545     0.8055       5.1213
1    6   11     12.000     96.2384    -0.1736    -1.1222       4.6754
1    7   13     12.000     93.7121    -0.1849    -0.8310       4.3886
1    8   15     12.000     92.1992    -0.1685     1.4376       4.2036
1    9   17     12.000     88.9479    -0.1957    -2.6682       4.0857
1   10   19     12.000     87.1063    -0.1847     1.1494       4.0130
1   11   21     12.000     85.4691    -0.1721     1.3497       3.9706
1   12   23     12.000     83.4872    -0.1703     0.1983       3.9478
1   13   25     12.000     81.0928    -0.1780    -0.8360       3.9368
1   14   27     12.000     78.6840    -0.1840    -0.6535       3.9322
1   15   29     12.000     76.7533    -0.1779     0.6632       3.9307
1   16   31     12.000     74.8173    -0.1735     0.4758       3.9303
1   17   33     12.000     73.1776    -0.1638     1.0604       3.9302
1   18   35     12.000     71.3944    -0.1598     0.4371       3.9301
1   19   37     12.000     68.8458    -0.1737    -1.5126       3.9300
1   20   39     12.000     66.4753    -0.1799    -0.6871       3.9299
1   21   41     12.000     64.3785    -0.1786     0.1502       3.9297
1   22   43     12.000     62.9310    -0.1633     1.6668       3.9296
1   23   45     12.000     62.0470    -0.1397     2.5784       3.9296
1   24   47     12.000     60.6745    -0.1330     0.7282       3.9296
1   25   49     12.000     59.0022    -0.1347    -0.1829       3.9295
1   26   51     12.000     56.8325    -0.1468    -1.3267       3.9295
1   27   53     12.000     55.2973    -0.1419     0.5438       3.9295
1   28   55     12.000     53.6019    -0.1417     0.0165       3.9295
1   29   57     12.000     52.4651    -0.1293     1.3513       3.9295
1   30   59     12.000     51.7908    -0.1101     2.1038       3.9295
1   31   61     12.000     50.6026    -0.1071     0.3174       3.9295
2    0    2      0.0      123.1348     0.0810
2    2    4     12.000    122.4821    -0.0544    -1.6245    3600.0022
2    3    6     12.000    120.9605    -0.0952    -0.9966       8.3853
2    4    8     12.000    118.2154    -0.1637    -2.1748       5.8473
2    5   10     12.000    116.7974    -0.1447     0.8319       5.1213
2    6   12     12.000    115.7090    -0.1259     1.1009       4.6754
2    7   14     12.000    114.5483    -0.1170     0.6568       4.3886
2    8   16     12.000    113.1856    -0.1160     0.0843       4.2036
2    9   18     12.000    111.6861    -0.1184    -0.2320       4.0857
2   10   20     12.000    109.9158    -0.1260    -0.7919       4.0130
2   11   22     12.000    108.6817    -0.1200     0.6479       3.9706
2   12   24     12.000    107.5498    -0.1133     0.7287       3.9478
2   13   26     12.000    105.9513    -0.1185    -0.5700       3.9368
2   14   28     12.000    104.4048    -0.1212    -0.2975       3.9322
2   15   30     12.000    102.5540    -0.1299    -0.9485       3.9307
2   16   32     12.000    100.6689    -0.1371    -0.7811       3.9303
2   17   34     12.000     99.1687    -0.1339     0.3474       3.9302
2   18   36     12.000     97.4578    -0.1362    -0.2492       3.9301
2   19   38     12.000     95.2066    -0.1497    -1.4783       3.9300
2   20   40     12.000     93.8084    -0.1410     0.9555       3.9299
2   21   42     12.000     92.4781    -0.1330     0.8666       3.9297
2   22   44     12.000     90.7845    -0.1352    -0.2328       3.9296
2   23   46     12.000     89.0024    -0.1387    -0.3833       3.9296
2   24   48     12.000     87.9807    -0.1246     1.5404       3.9296
2   25   50     12.000     85.7274    -0.1412    -1.8180       3.9295
2   26   52     12.000     82.8544    -0.1671    -2.8246       3.9295
2   27   54     12.000     80.5045    -0.1747    -0.8260       3.9295
2   28   56     12.000     79.5839    -0.1489    -2.8182       3.9295
2   29   58     12.000     77.7355    -0.1502    -0.1490       3.9295
2   30   60     12.000     75.9437    -0.1500     0.0261       3.9295
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                    TARGET NUMBER   1

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER  1

 K  FREQ     PRF    PW      THETAD       THTD        SLAD       SLOD

 1 1197.0 150.0 3.50   106.6854   106.6854    33.4991 -118.5004
 3 1197.0 150.0 3.50   104.1513   104.1513    33.4670 -118.5002
 5 1197.0 150.0 3.50   102.4055   102.3046    33.4326 -118.5007
 7 1197.0 150.0 3.50   100.3478   100.2979    33.4000 -118.5012
 9 1197.0 150.0 3.50    99.0287    98.7523    33.3669 -118.5006
11 1197.0 150.0 3.50    95.7764    96.2384    33.3334 -118.4993
13 1197.0 150.0 3.50    93.3238    93.7121    33.3003 -118.4999
15 1197.0 150.0 3.50    92.9314    92.1992    33.2663 -118.5003
17 1197.0 150.0 3.50    87.5094    88.9479    33.2329 -118.4994
19 1197.0 150.0 3.50    87.7487    87.1063    33.2001 -118.4999
21 1197.0 150.0 3.50    86.2396    85.4691    33.1664 -118.5005
23 1197.0 150.0 3.50    83.6018    83.4872    33.1337 -118.4999
25 1197.0 150.0 3.50    80.6074    81.0928    33.1003 -118.5002
27 1197.0 150.0 3.50    78.3036    78.6840    33.0670 -118.5003
29 1197.0 150.0 3.50    77.1396    76.7533    33.0337 -118.5002
31 1197.0 150.0 3.50    75.0945    74.8173    33.0003 -118.5010
33 1197.0 150.0 3.50    73.7954    73.1776    32.9669 -118.5000
35 1197.0 150.0 3.50    71.6491    71.3944    32.9339 -118.4995
37 1197.0 150.0 3.50    67.9644    68.8458    32.8998 -118.4998
39 1197.0 150.0 3.50    66.0749    66.4753    32.8670 -118.5007
41 1197.0 150.0 3.50    64.4660    64.3785    32.8340 -118.4997
43 1197.0 150.0 3.50    63.9025    62.9310    32.8003 -118.5001
45 1197.0 150.0 3.50    63.5497    62.0470    32.7663 -118.5001
47 1197.0 150.0 3.50    61.0990    60.6745    32.7334 -118.4997
49 1197.0 150.0 3.50    58.8956    59.0022    32.6994 -118.4995
51 1197.0 150.0 3.50    56.0593    56.8325    32.6665 -118.4995
53 1197.0 150.0 3.50    55.6143    55.2973    32.6332 -118.5004
55 1197.0 150.0 3.50    53.6115    53.6019    32.5998 -118.4998
57 1197.0 150.0 3.50    53.2528    52.4651    32.5663 -118.5007
59 1197.0 150.0 3.50    53.0171    51.7908    32.5334 -118.5005
61 1197.0 150.0 3.50    50.7876    50.6026    32.5010 -118.5002

 SMOOTHED INITIAL BEARING ANGLE =  106.68590 N

   FILTERED FINAL BEARING ANGLE =   50.60260 W


         VECTOR METHOD SOLUTION OF EMITTER LOCATION

                EMITTER LATITUDE =   33.22765 N

               EMITTER LONGITUDE =-117.43607 W
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                     TARGET NUMBER   2

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER   2

  K   FREQ    PRF    PW      THETAD      THTD       SLAD      SLOD

  2 1212.0 250.0 3.00   123.1348  123.1348   33.4856 -118.5002
  4 1212.0 250.0 3.00   122.4821  122.4821   33.4498 -118.5004
  6 1212.0 250.0 3.00   120.8329  120.9605   33.4160 -118.5004
  8 1212.0 250.0 3.00   117.6429  118.2154   33.3836 -118.5015
 10 1212.0 250.0 3.00   117.0829  116.7974   33.3499 -118.4998
 12 1212.0 250.0 3.00   116.1623  115.7090   33.3168 -118.4997
 14 1212.0 250.0 3.00   114.8552  114.5483   33.2832 -118.4999
 16 1212.0 250.0 3.00   113.2285  113.1856   33.2496 -118.4999
 18 1212.0 250.0 3.00   111.5610  111.6861   33.2163 -118.4996
 20 1212.0 250.0 3.00   109.4732  109.9158   33.1830 -118.5004
 22 1212.0 250.0 3.00   109.0516  108.6817   33.1502 -118.5002
 24 1212.0 250.0 3.00   107.9706  107.5498   33.1168 -118.5001
 26 1212.0 250.0 3.00   105.6203  105.9513   33.0837 -118.5005
 28 1212.0 250.0 3.00   104.2317  104.4048   33.0503 -118.5001
 30 1212.0 250.0 3.00   102.0015  102.5540   33.0171 -118.5008
 32 1212.0 250.0 3.00   100.2138  100.6689   32.9836 -118.5007
 34 1212.0 250.0 3.00    99.3712   99.1687   32.9505 -118.4994
 36 1212.0 250.0 3.00    97.3126   97.4578   32.9167 -118.4995
 38 1212.0 250.0 3.00    94.3452   95.2066   32.8835 -118.5000
 40 1212.0 250.0 3.00    94.3653   93.8084   32.8505 -118.5002
 42 1212.0 250.0 3.00    92.9832   92.4781   32.8174 -118.4997
 44 1212.0 250.0 3.00    90.6488   90.7845   32.7829 -118.5002
 46 1212.0 250.0 3.00    88.7791   89.0024   32.7499 -118.4998
 48 1212.0 250.0 3.00    88.8786   87.9807   32.7166 -118.4993
 50 1212.0 250.0 3.00    84.6678   85.7274   32.6828 -118.4995
 52 1212.0 250.0 3.00    81.2080   82.8544   32.6499 -118.4999
 54 1212.0 250.0 3.00    80.0231   80.5045   32.6162 -118.5000
 56 1212.0 250.0 3.00    81.2266   79.5839   32.5830 -118.5002
 58 1212.0 250.0 3.00    77.6486   77.7355   32.5498 -118.5007
 60 1212.0 250.0 3.00    75.9589   75.9437   32.5172 -118.5006

 SMOOTHED INITIAL BEARING ANGLE =  123.13492 N

   FILTERED FINAL BEARING ANGLE =   75.94370 W


          VECTOR METHOD SOLUTION OF EMITTER LOCATION

                EMITTER LATITUDE =   32.77921 N

               EMITTER LONGITUDE =-117.22505 W




****************************************************************************************************
****************************************************************************************************
****************************************************************************************************
```

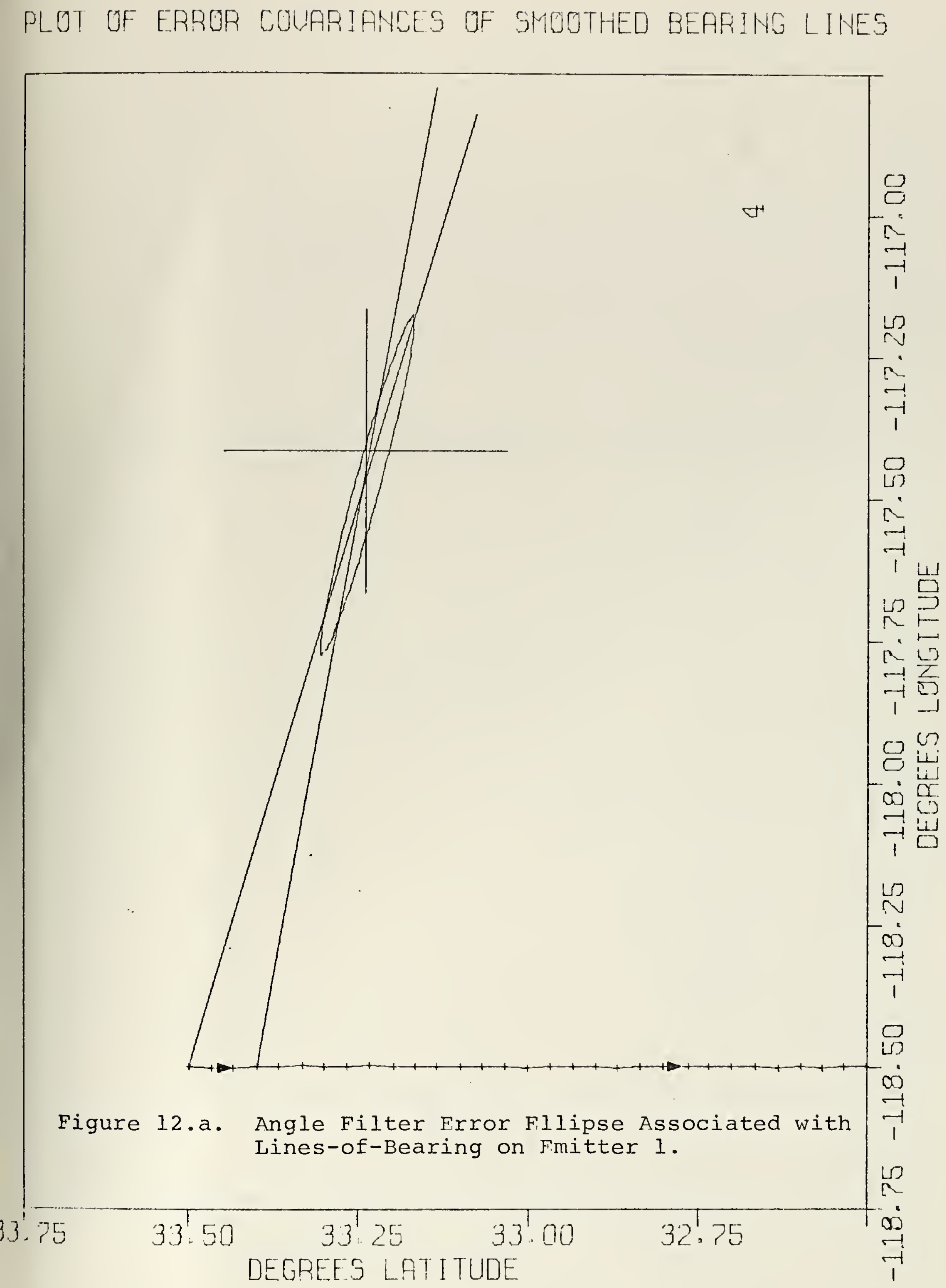


Figure 12.a. Angle Filter Error Ellipse Associated with Lines-of-Bearing on Emitter 1.

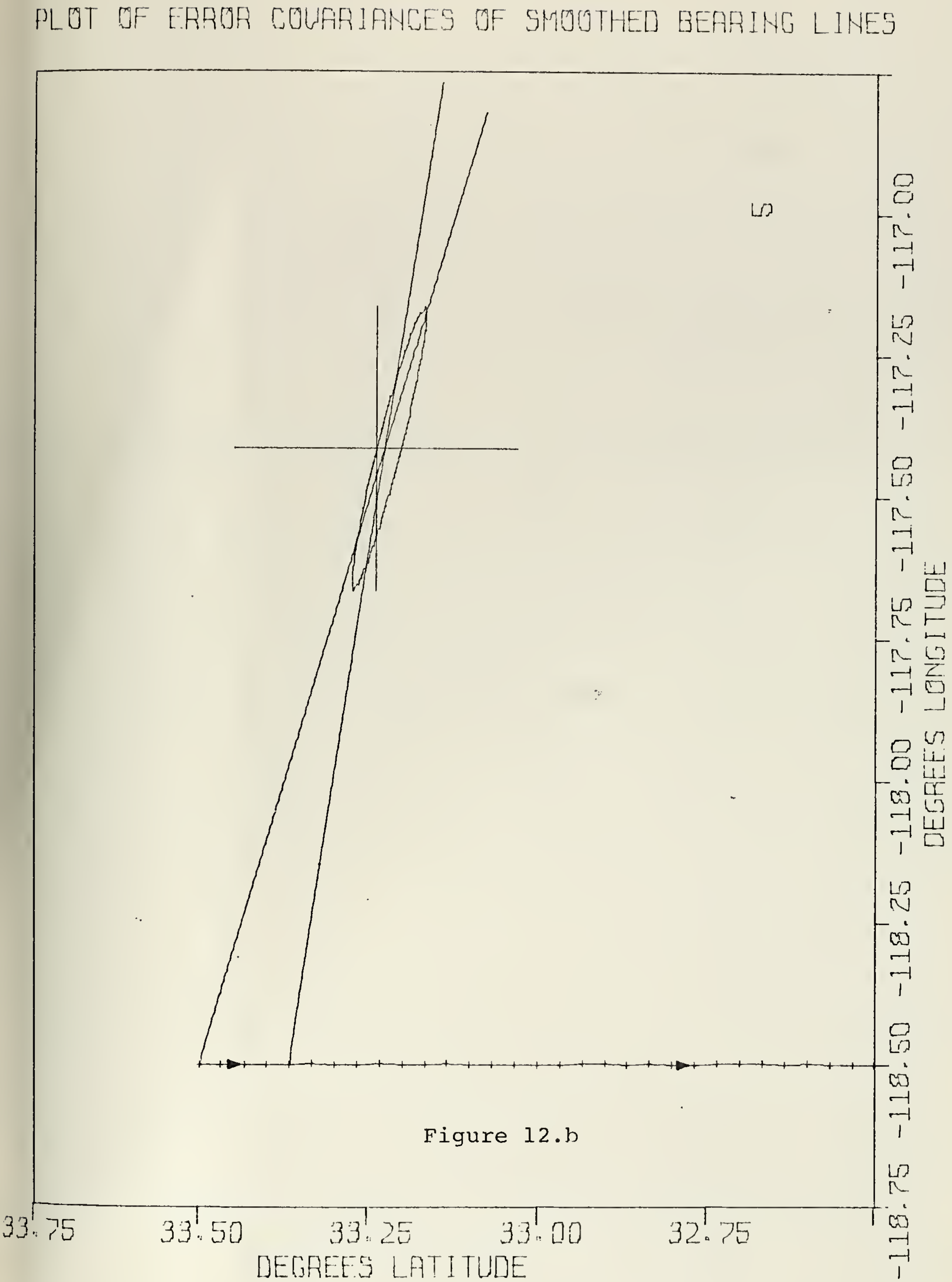

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
5
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE

Figure 12.b

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

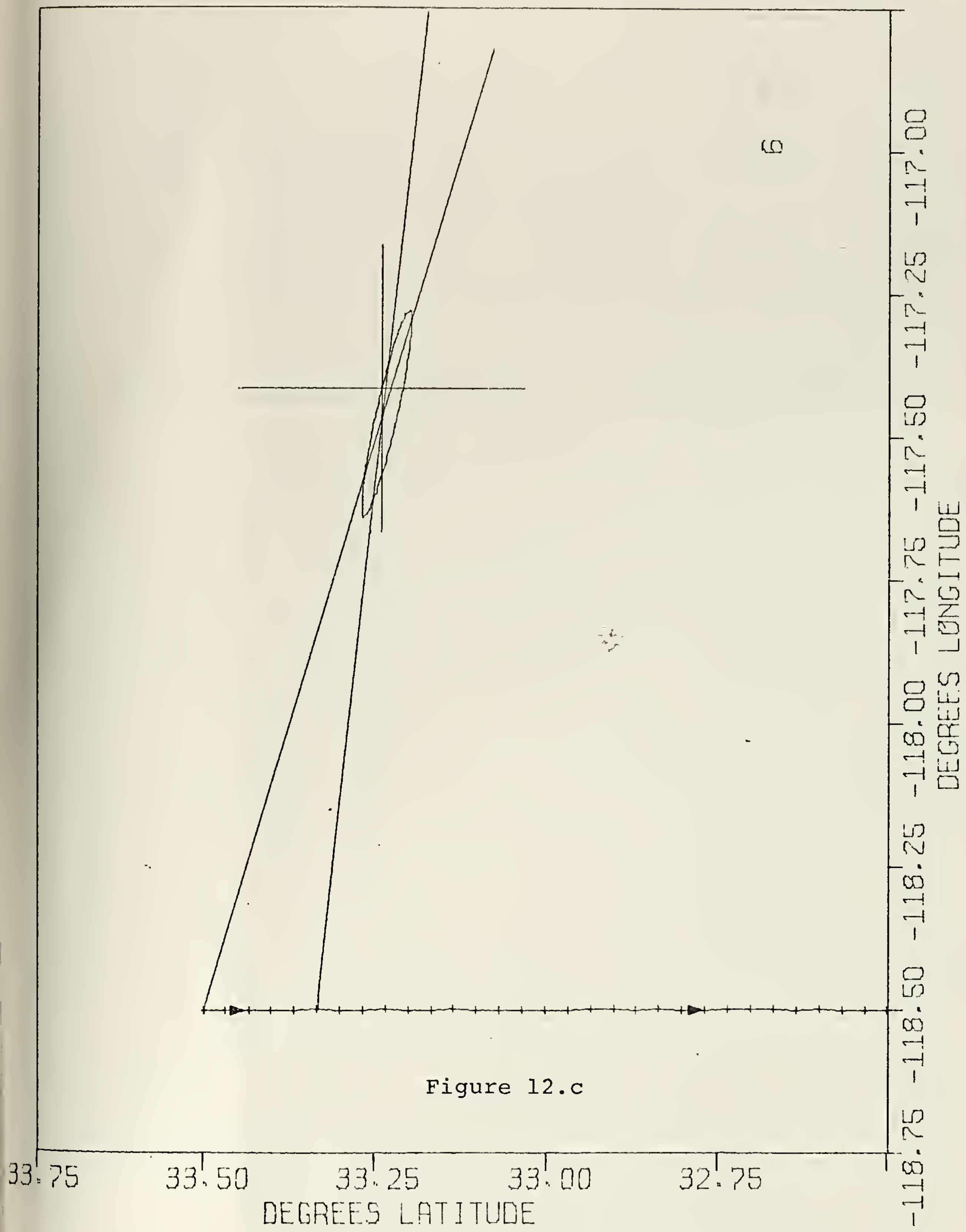


Figure 12.c

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

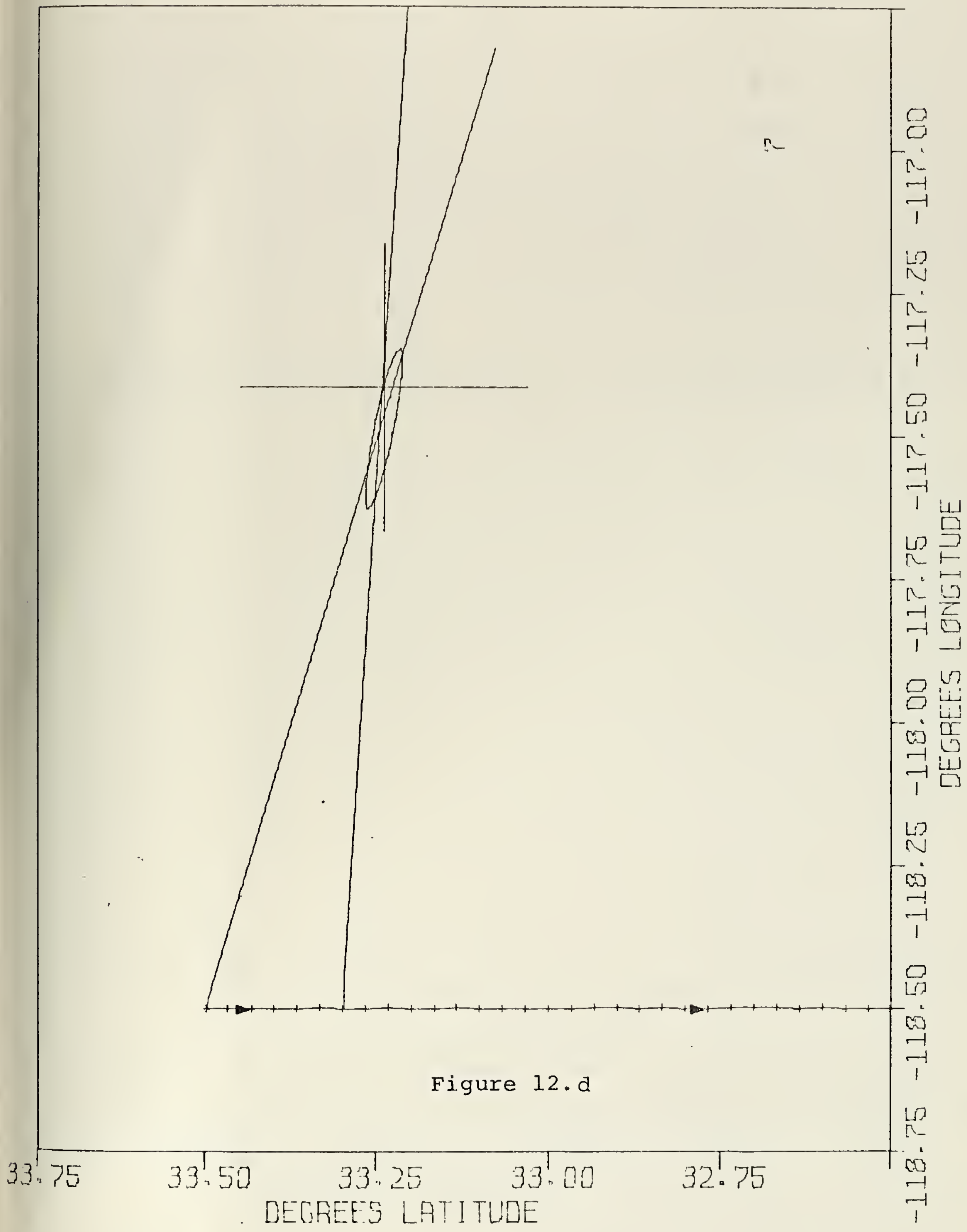


Figure 12.d

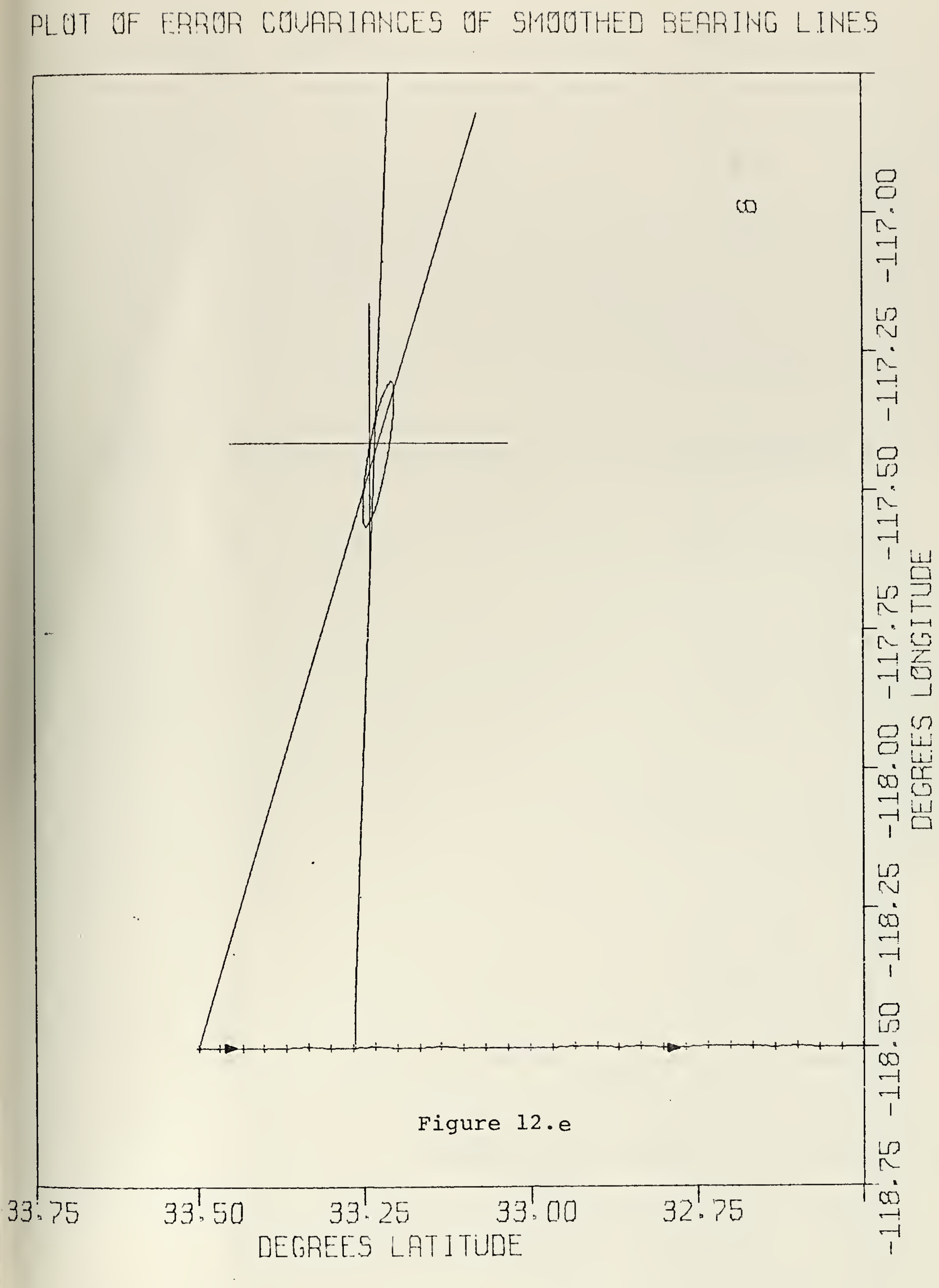

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
8
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE

Figure 12.e

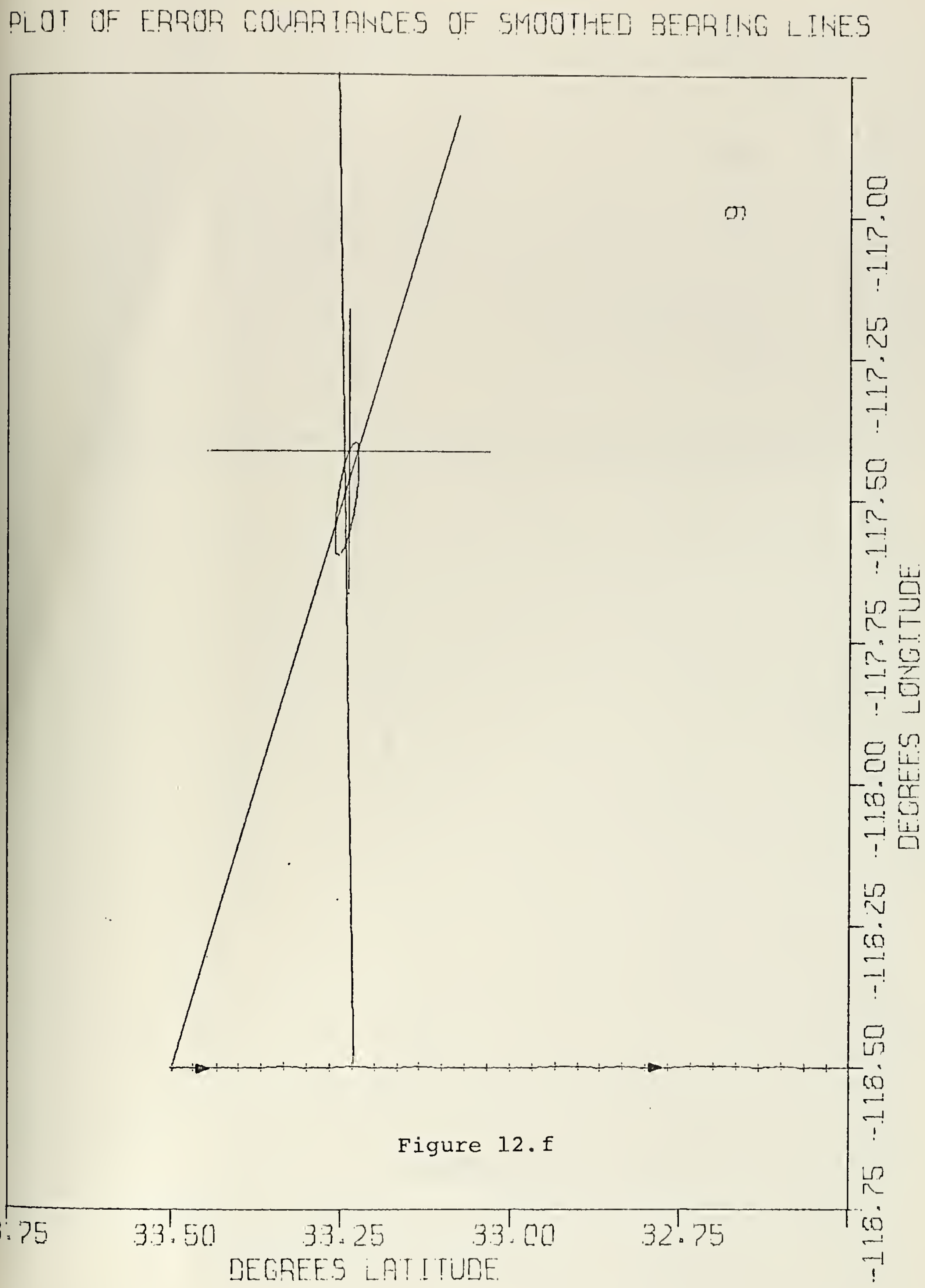

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
9
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 12.f

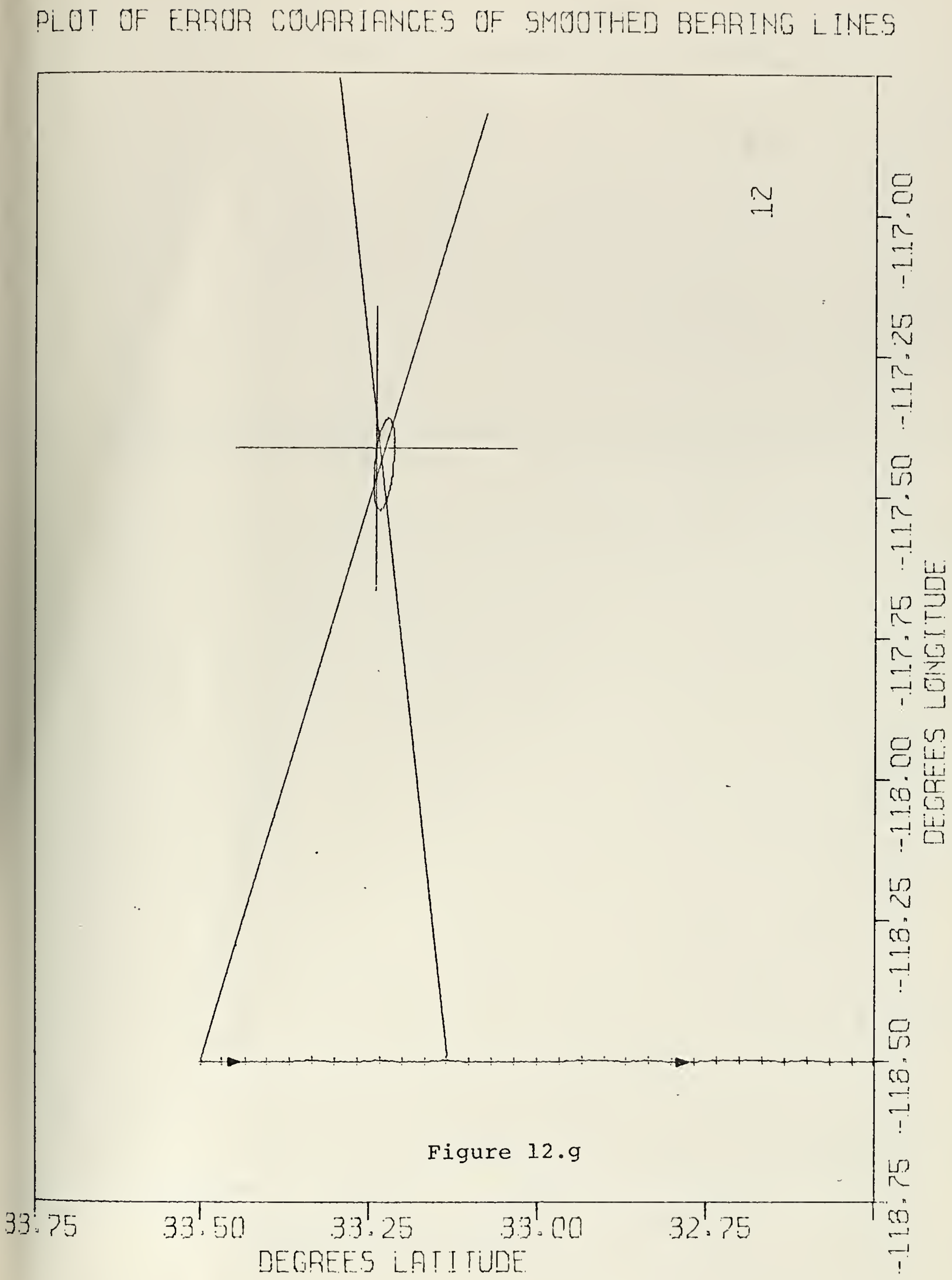

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
12
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 12.g

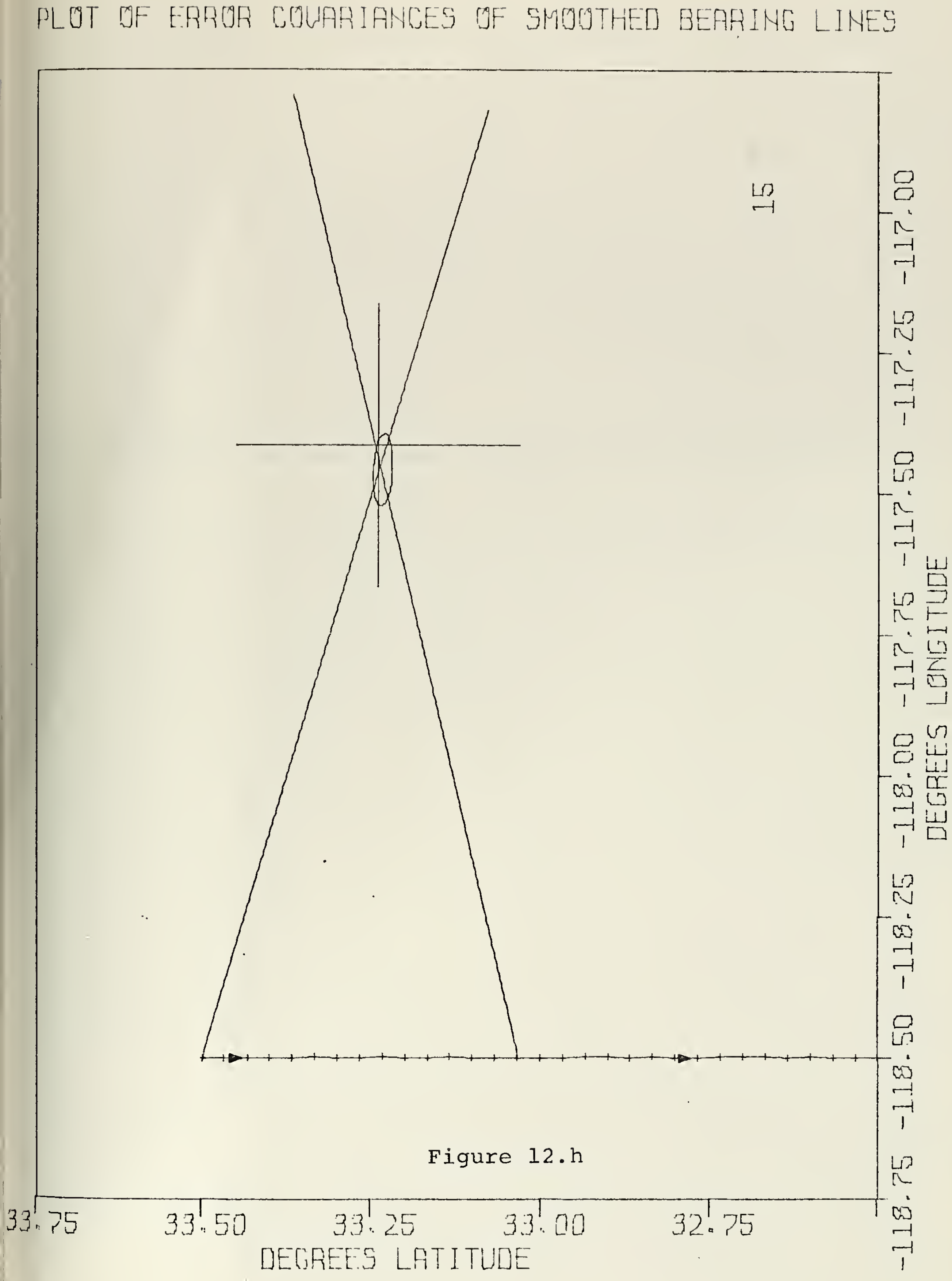

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
15
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 12.h

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

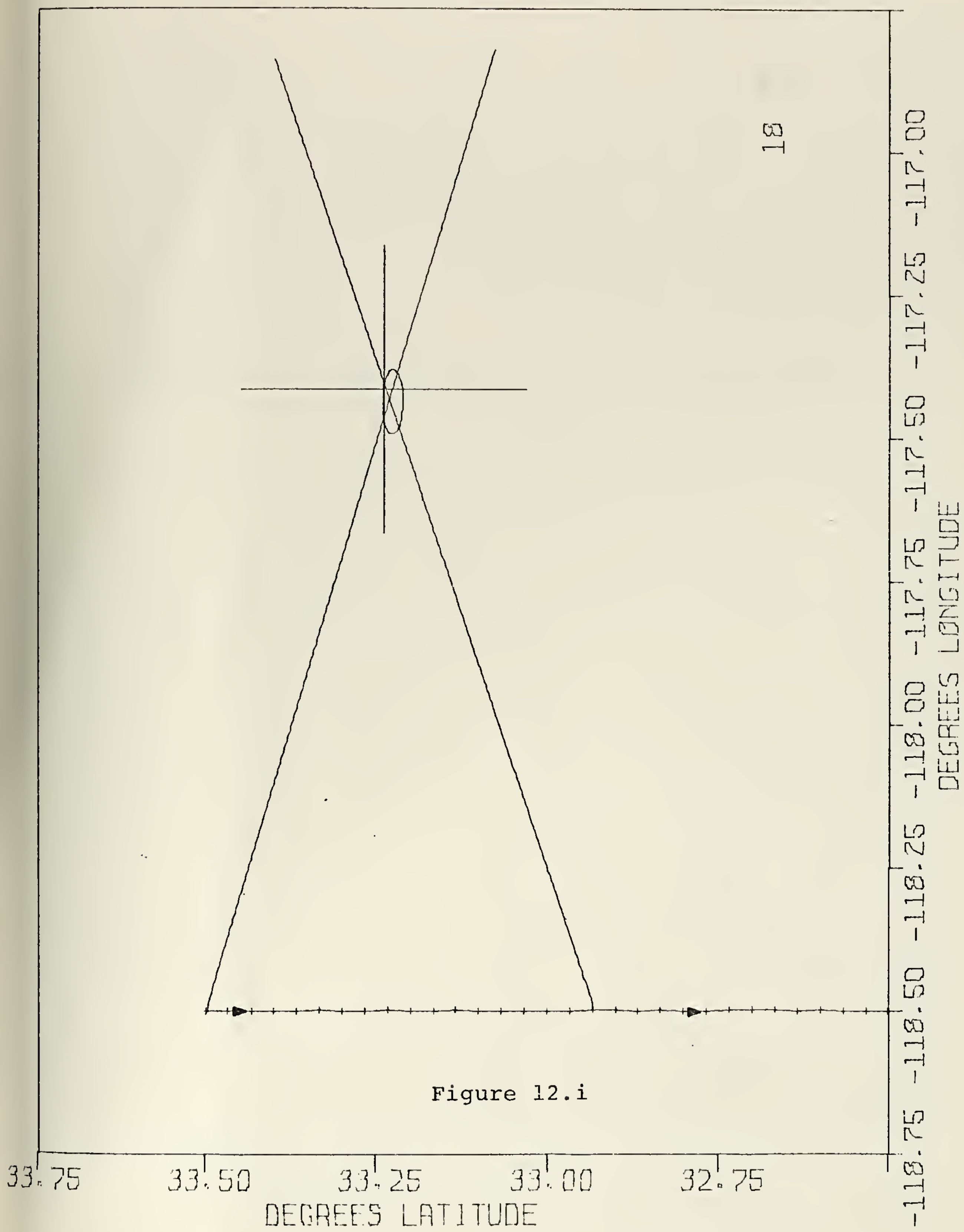


Figure 12.i

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

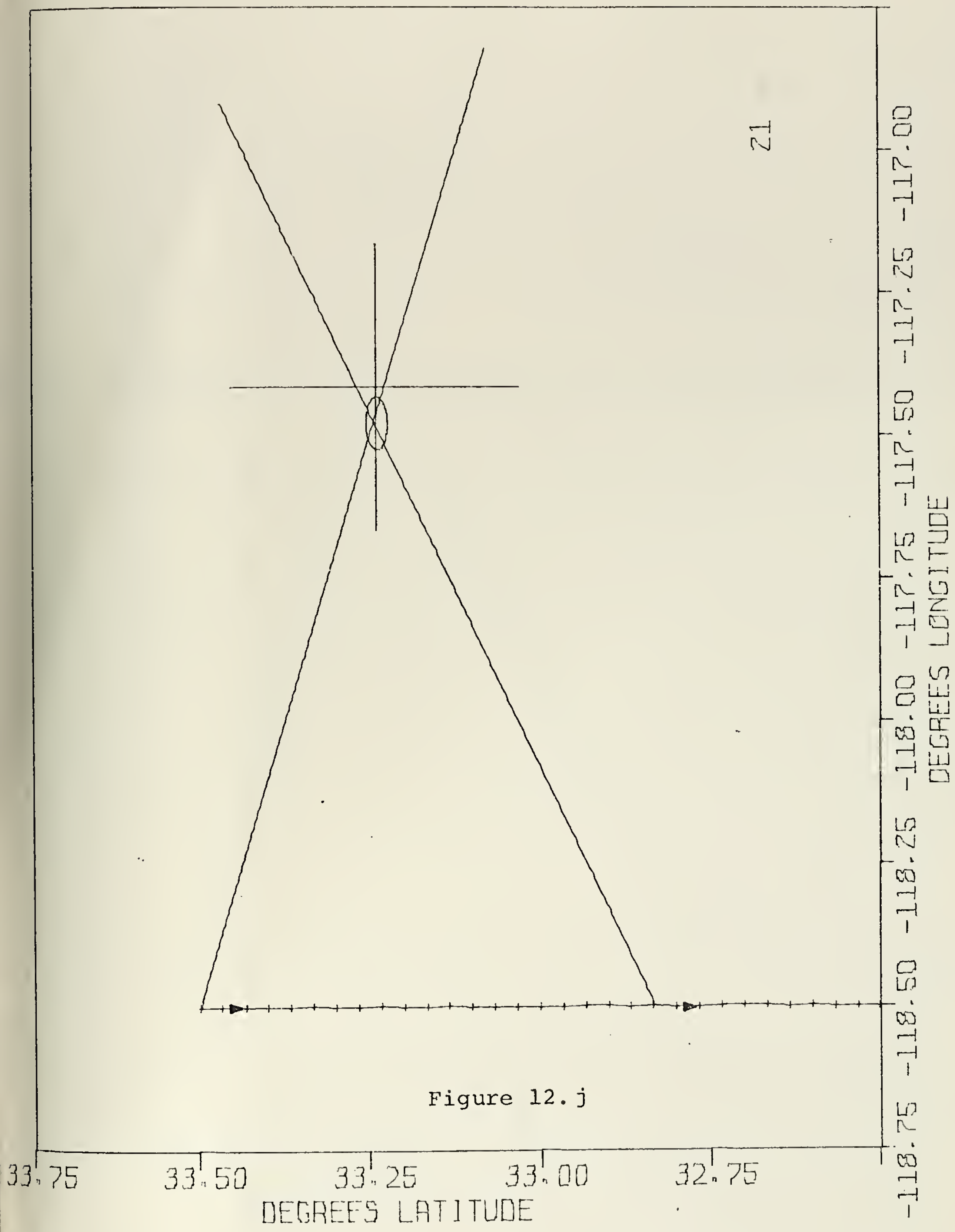


Figure 12.j

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

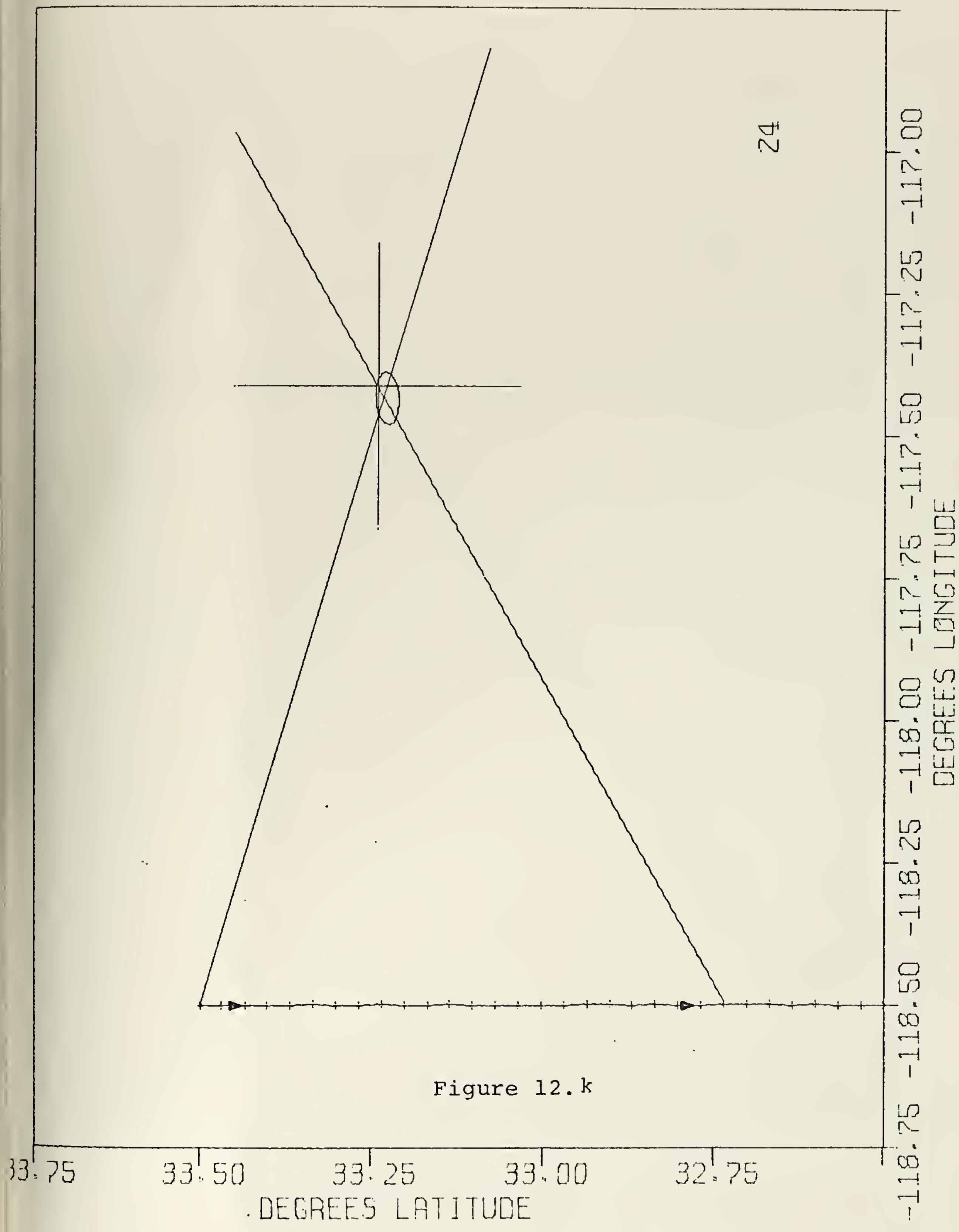
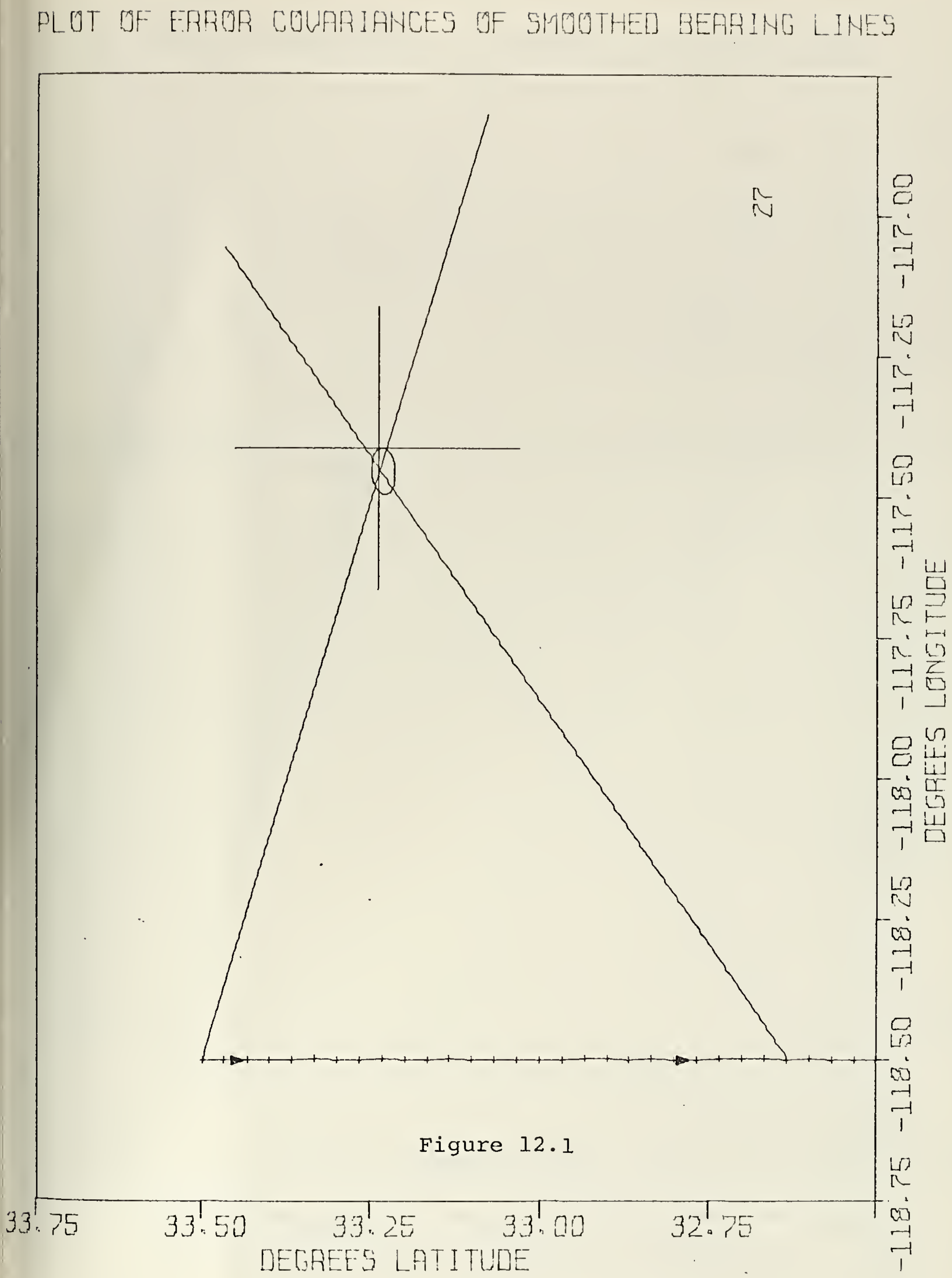


Figure 12.k



PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
27
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 12.1

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

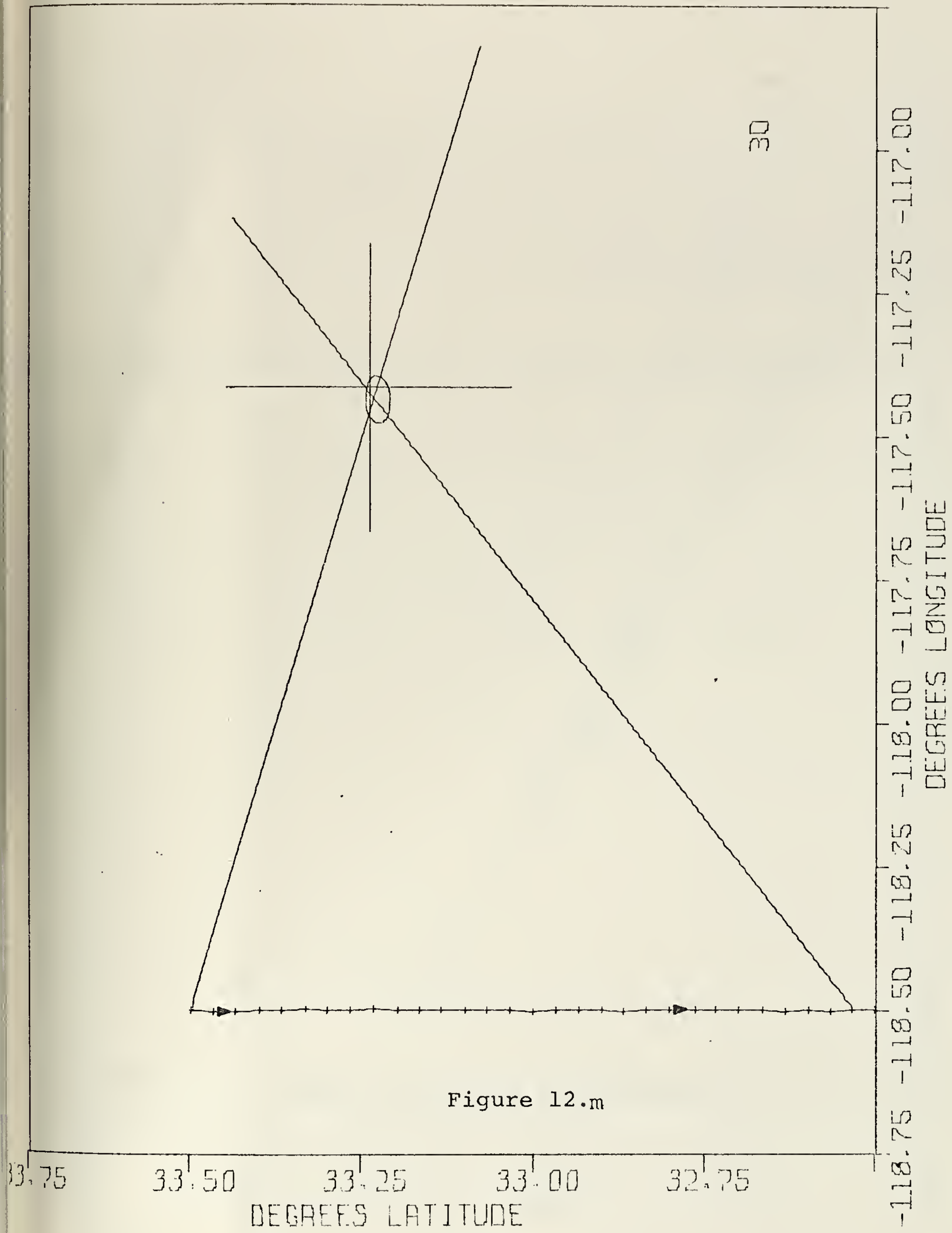


Figure 12.m

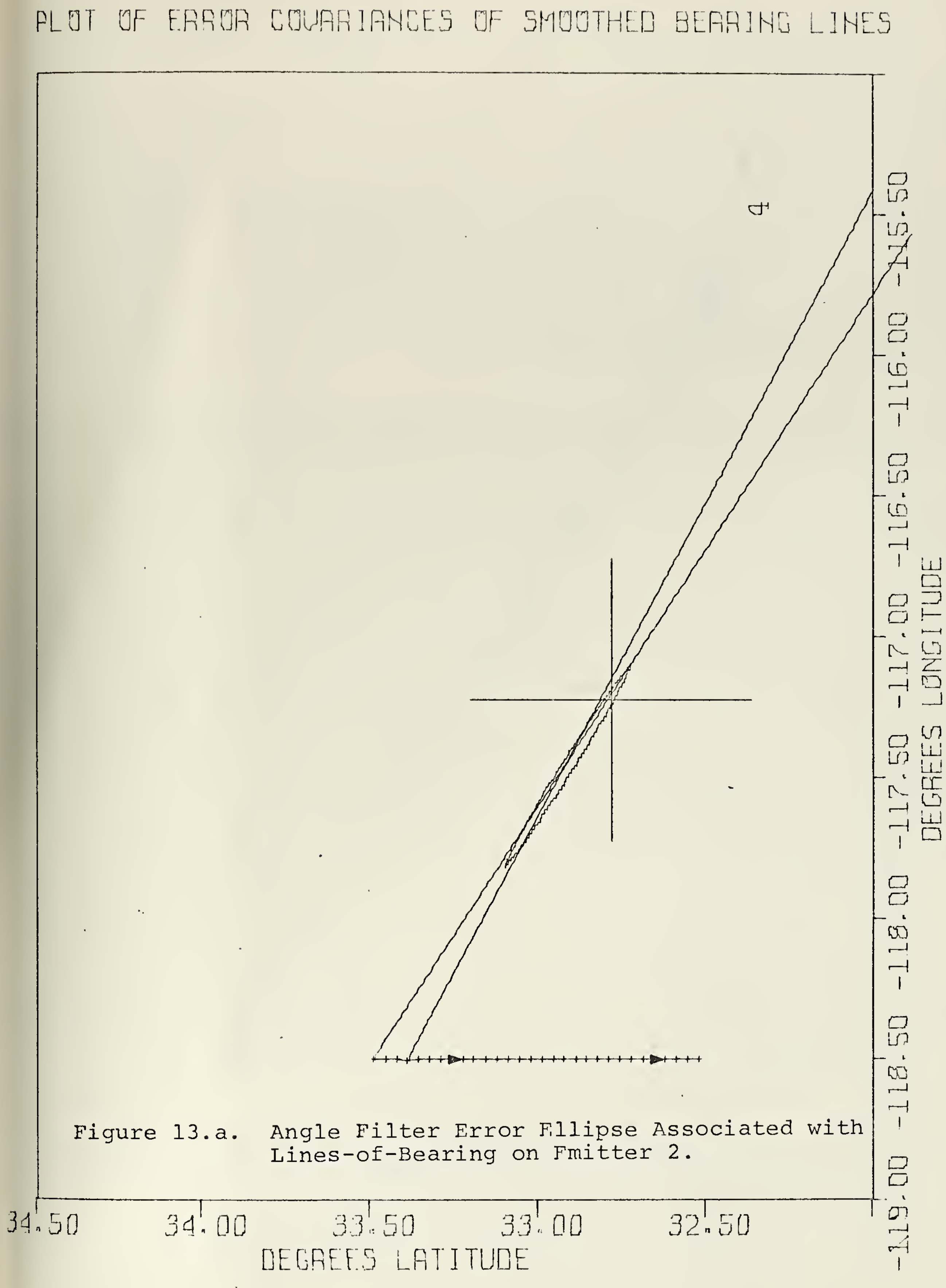


Figure 13.a. Angle Filter Error Ellipse Associated with Lines-of-Bearing on Emitter 2.

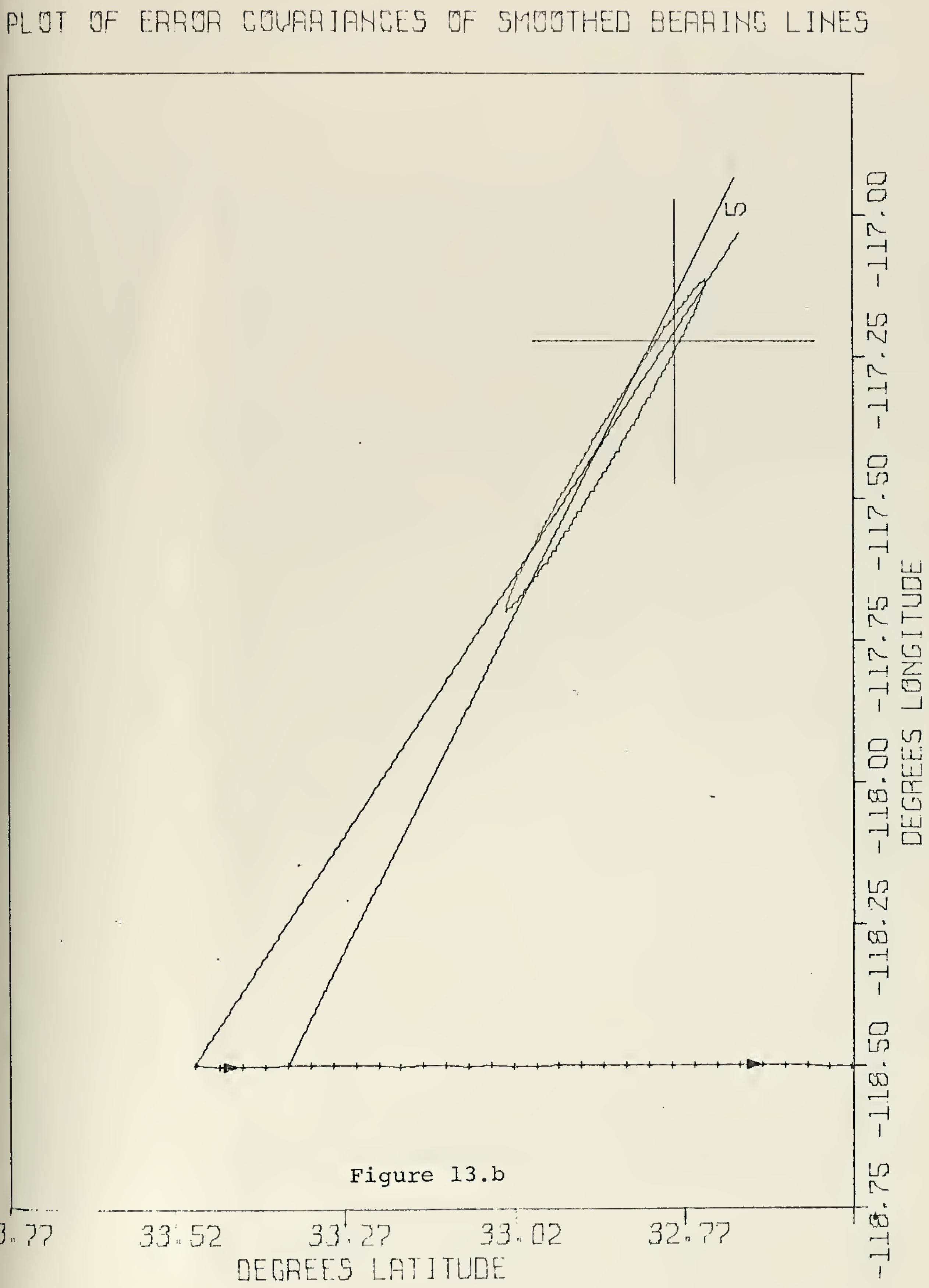

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
5
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE

Figure 13.b

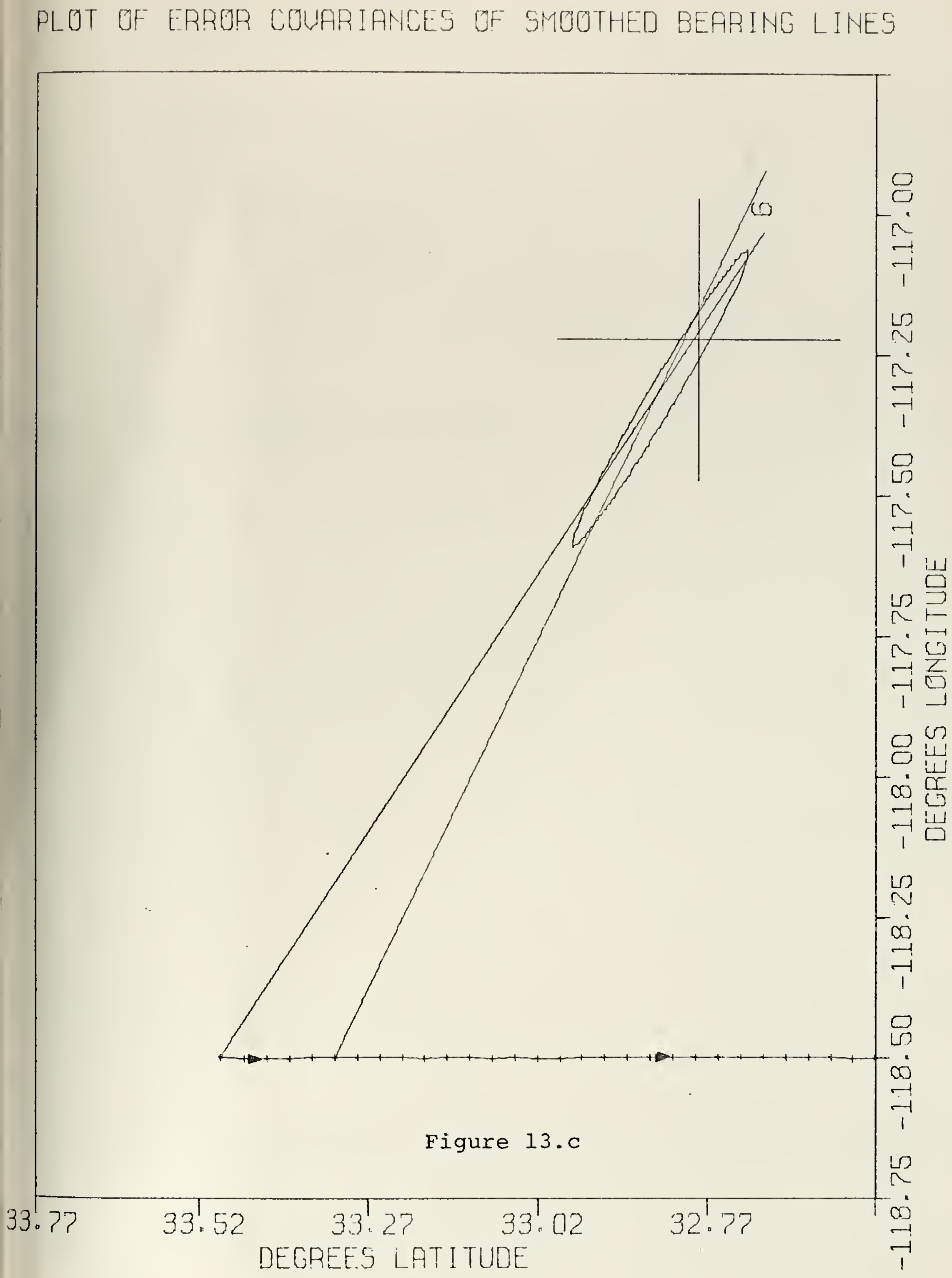

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
6
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE

Figure 13.c

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

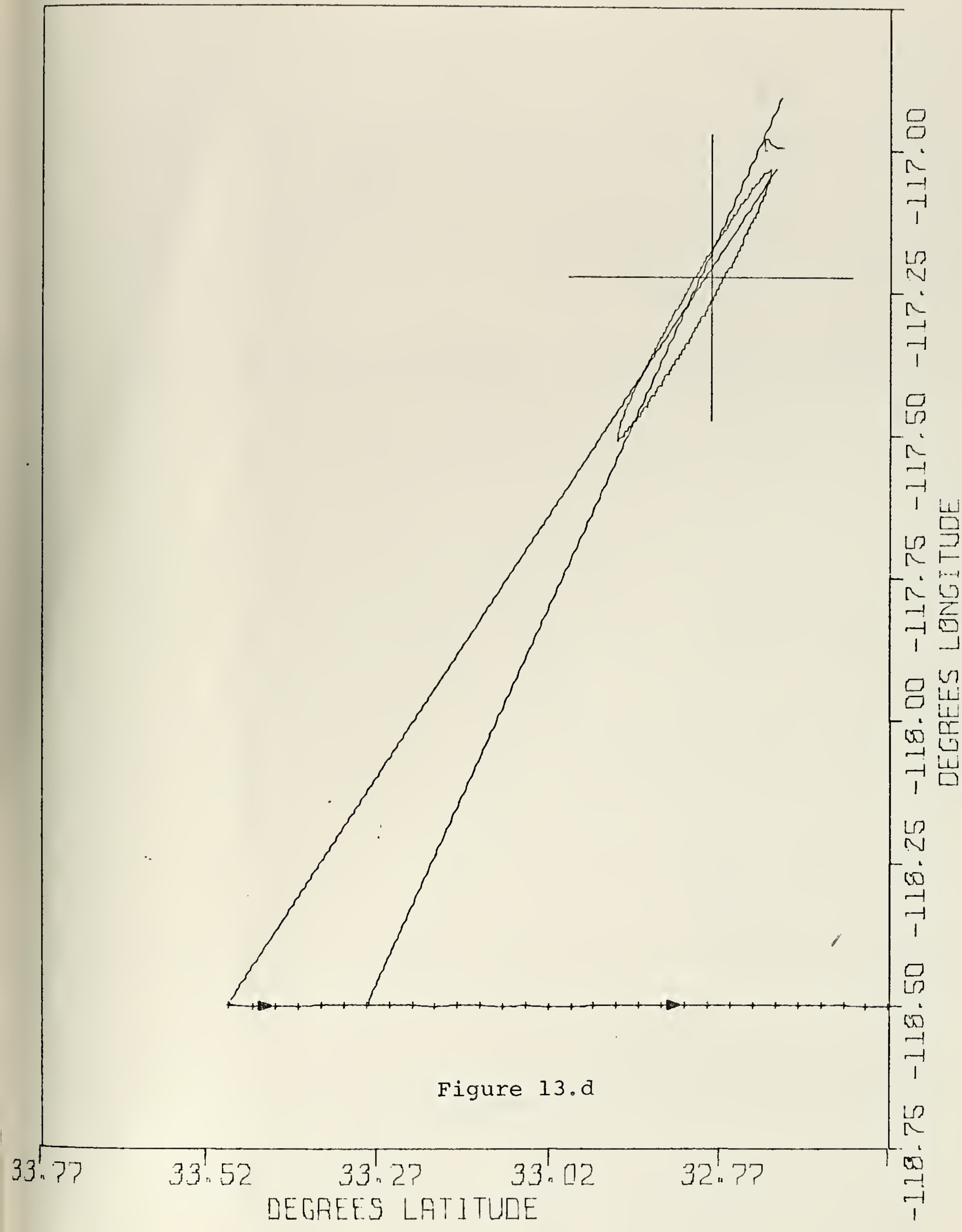


Figure 13.d

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

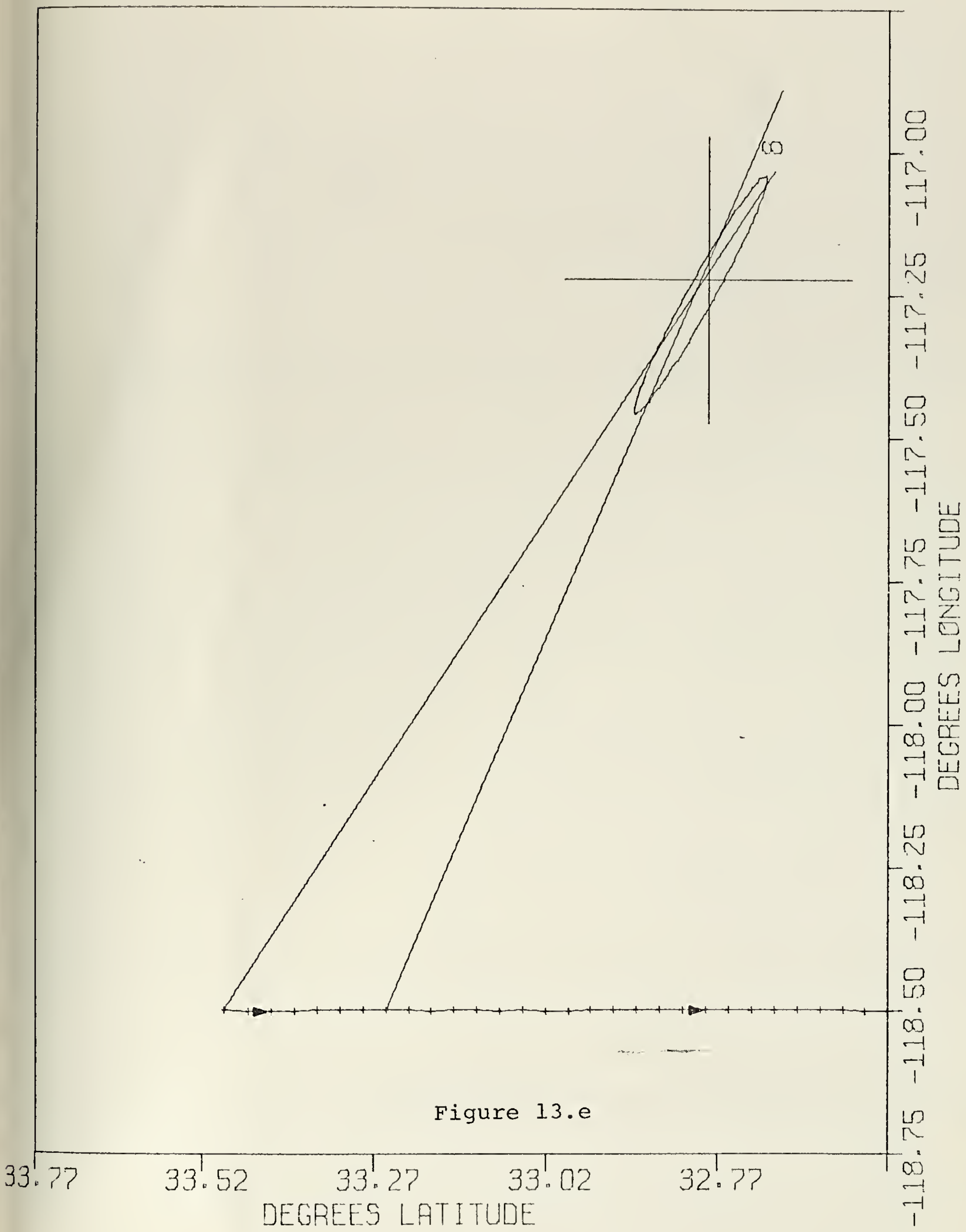


Figure 13.e

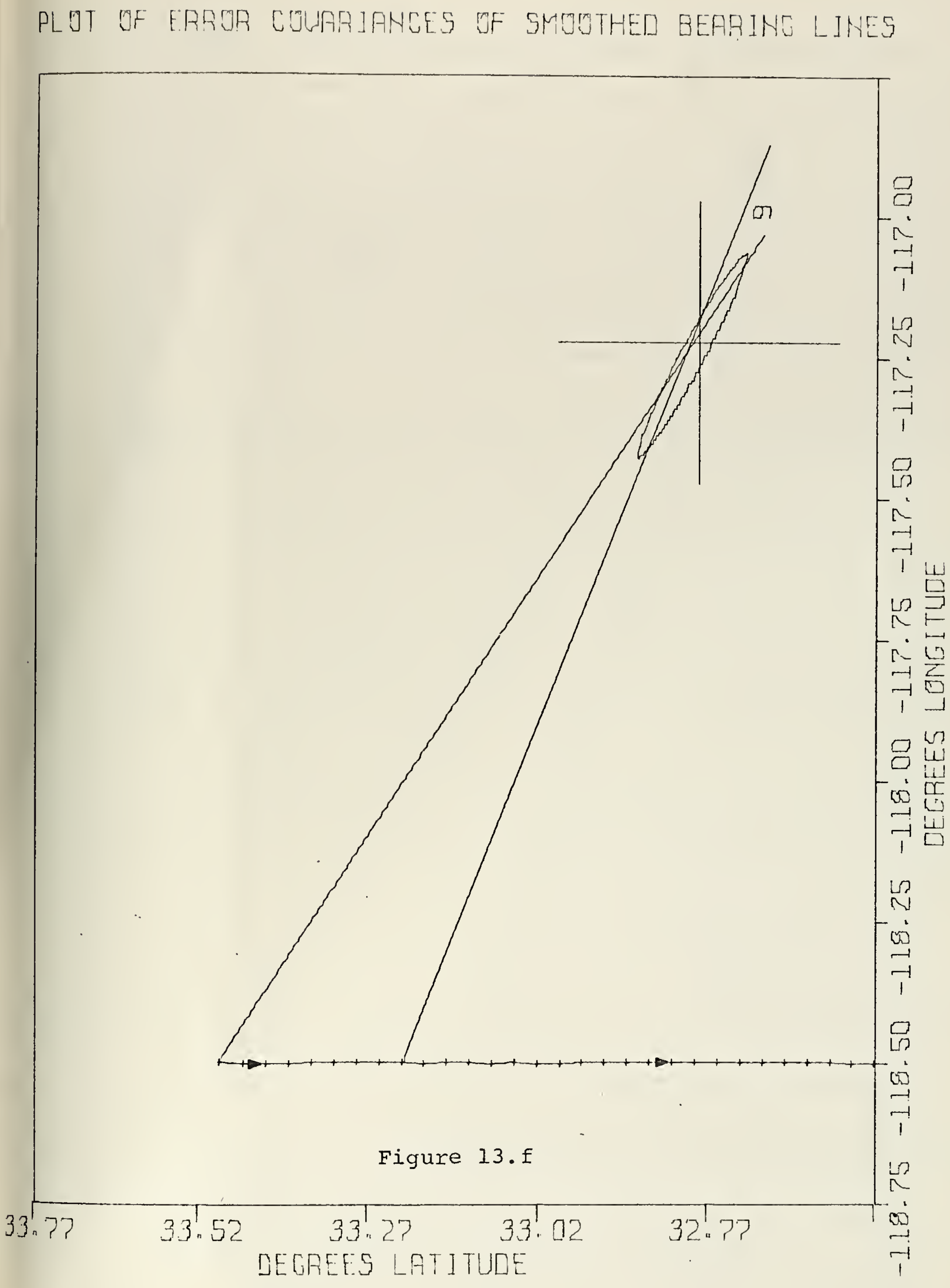

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
9
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE

Figure 13.f

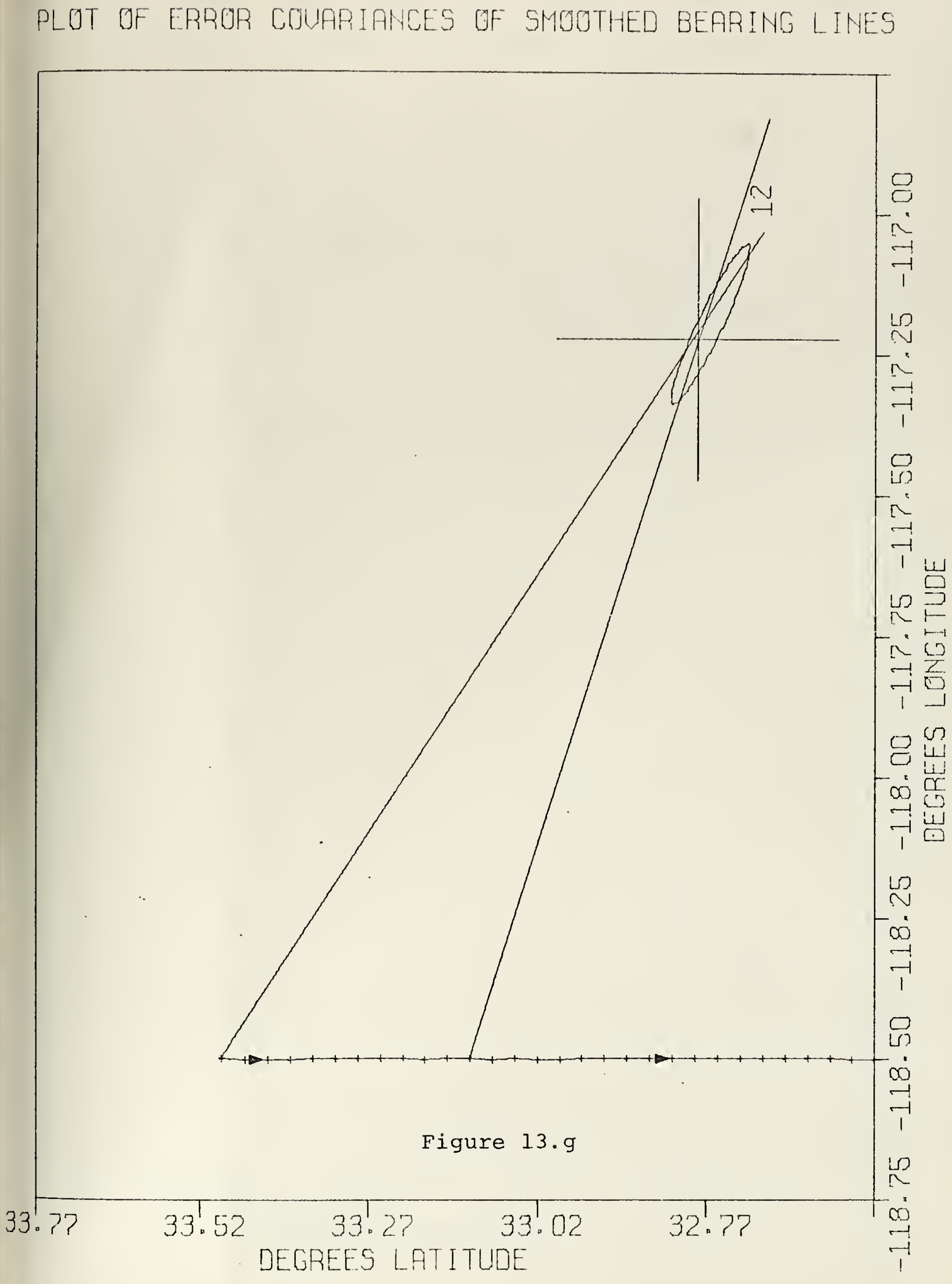

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
12
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE

Figure 13.g

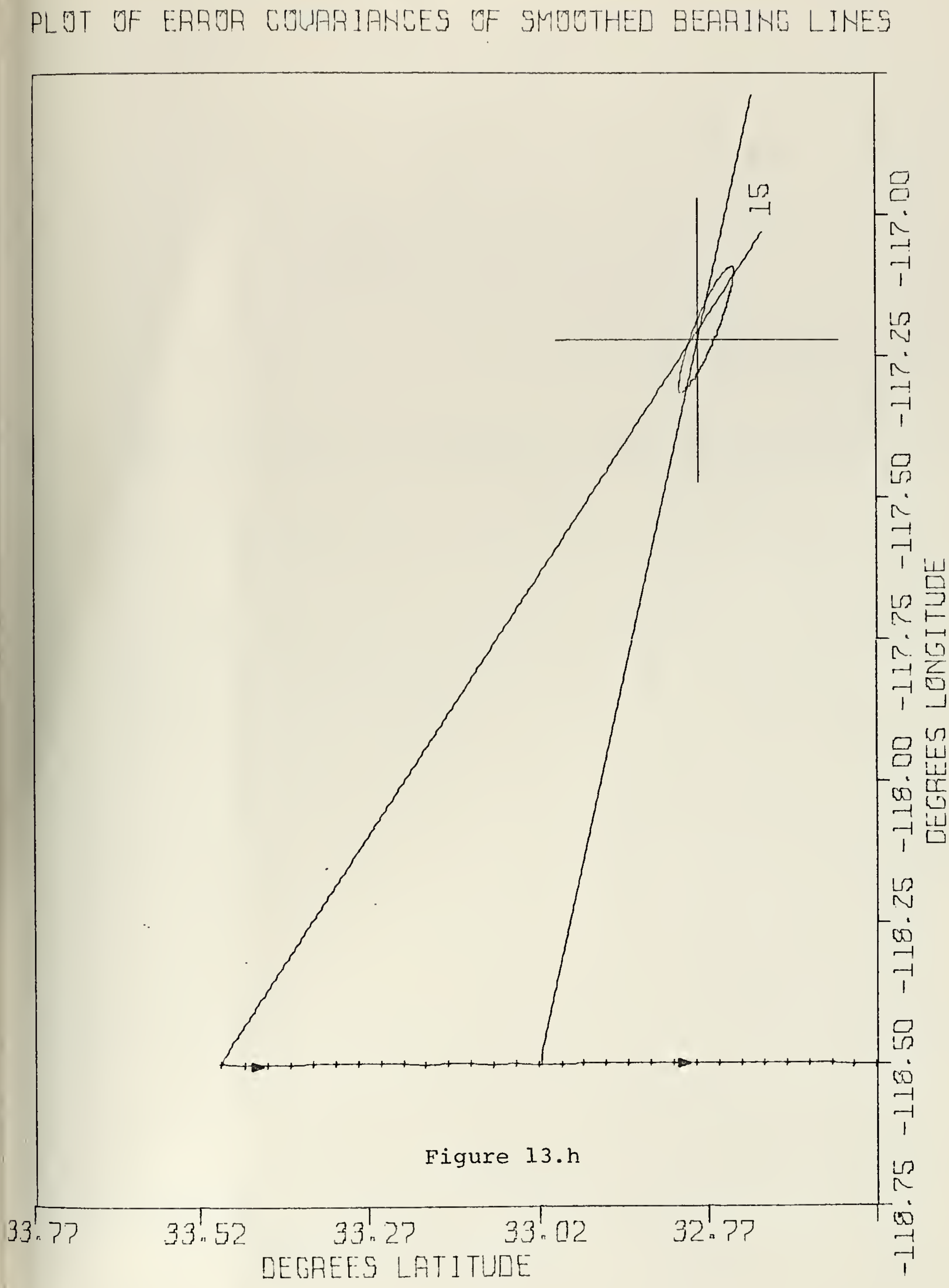

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
15
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE
-118.75
-118.50
-118.25
-118.00
-117.75
-117.50
-117.25
-117.00
DEGREES LONGITUDE

Figure 13.h

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

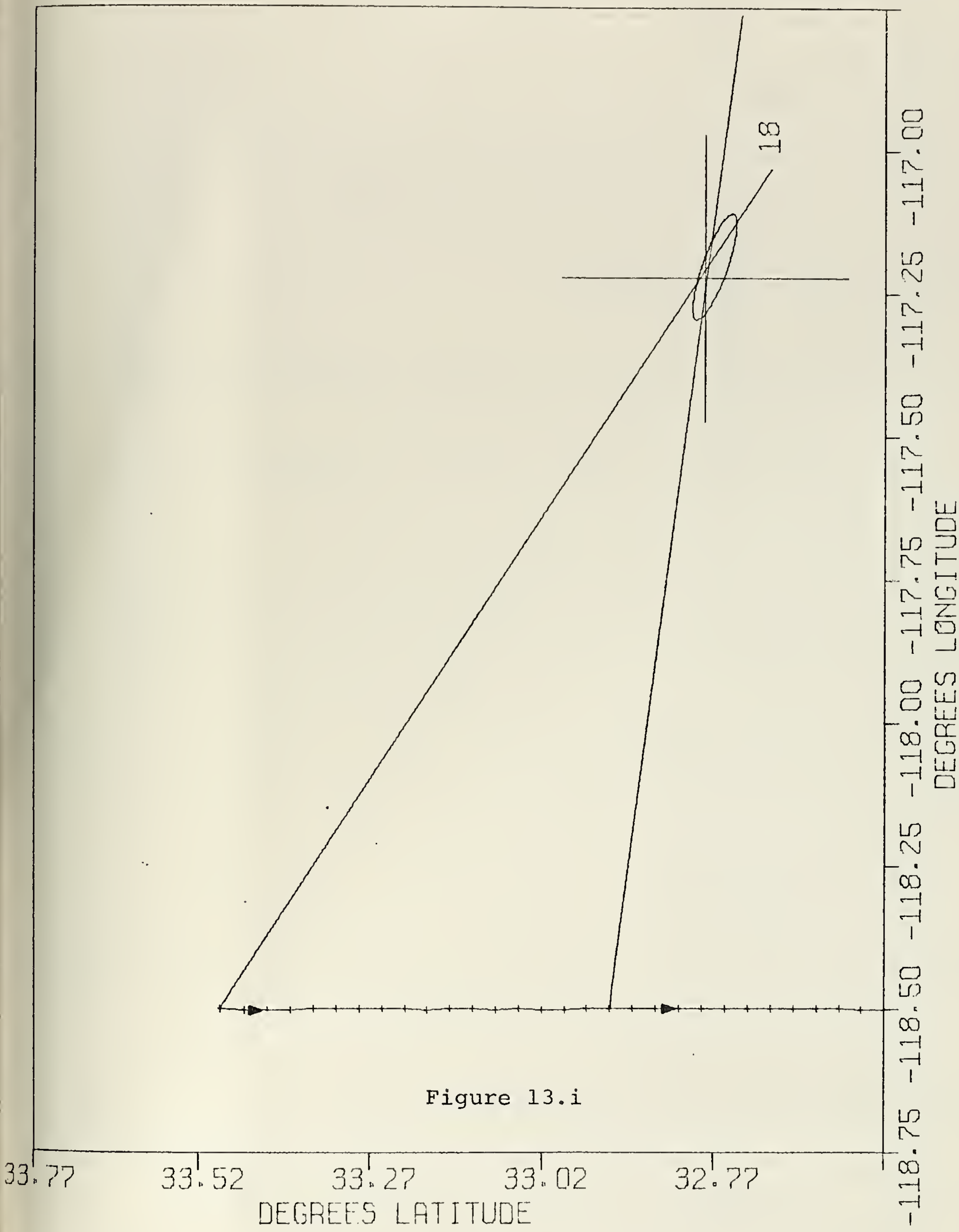


Figure 13.i

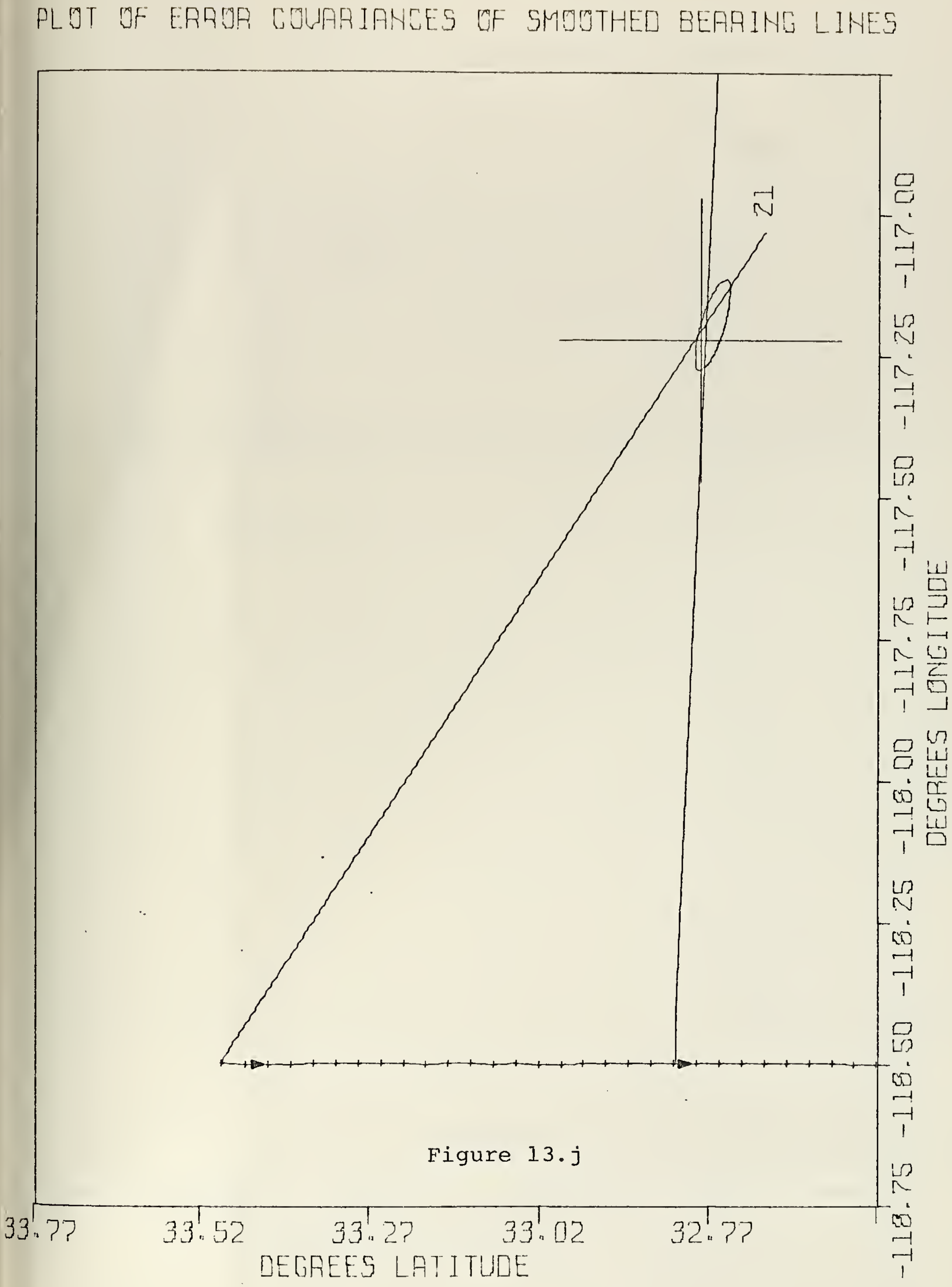

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
21
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE

Figure 13.j

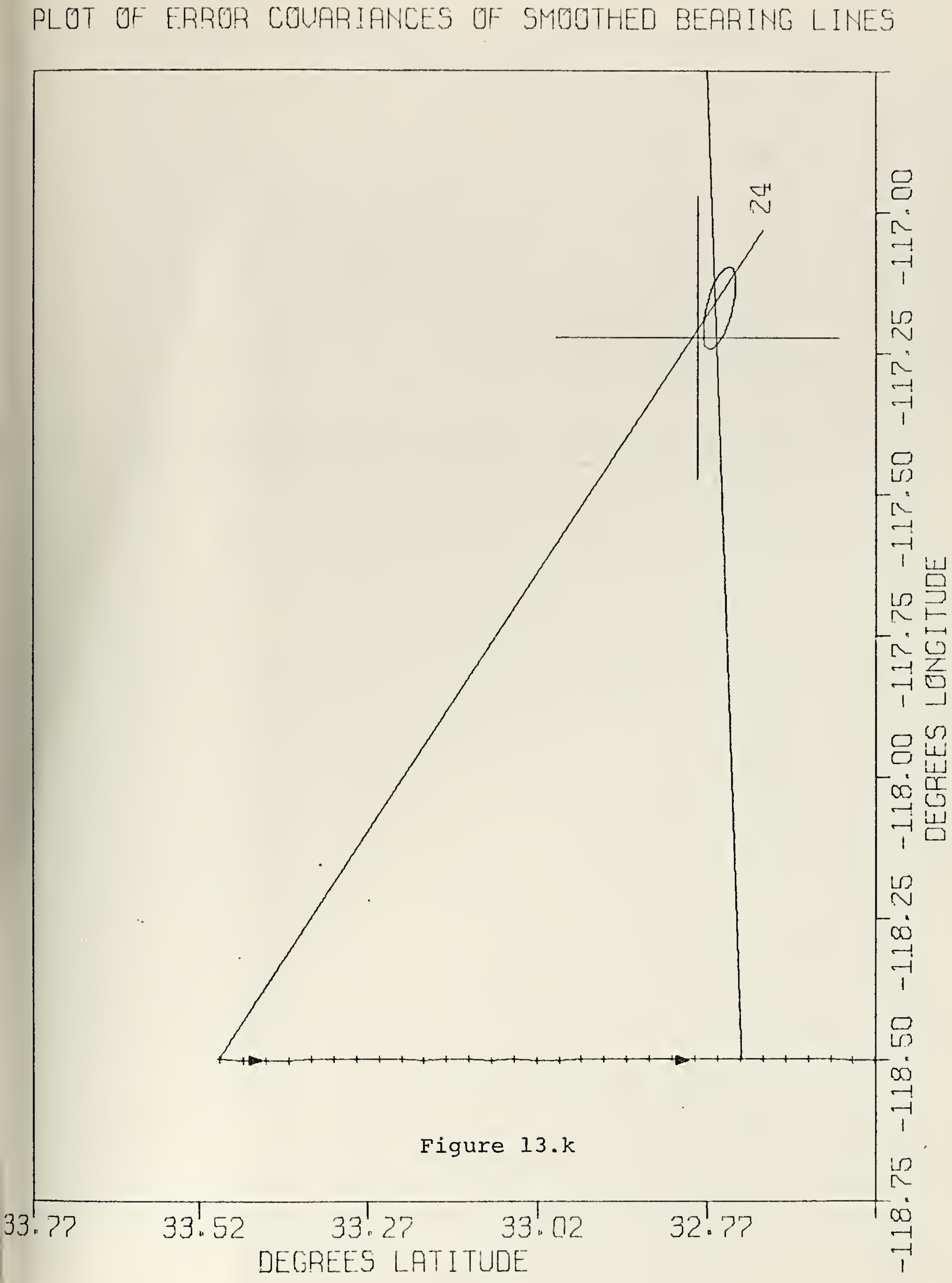

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES
24
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE
-118.75
-118.50
-118.25
-118.00
-117.75
-117.50
-117.25
-117.00
DEGREES LONGITUDE

Figure 13.k

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

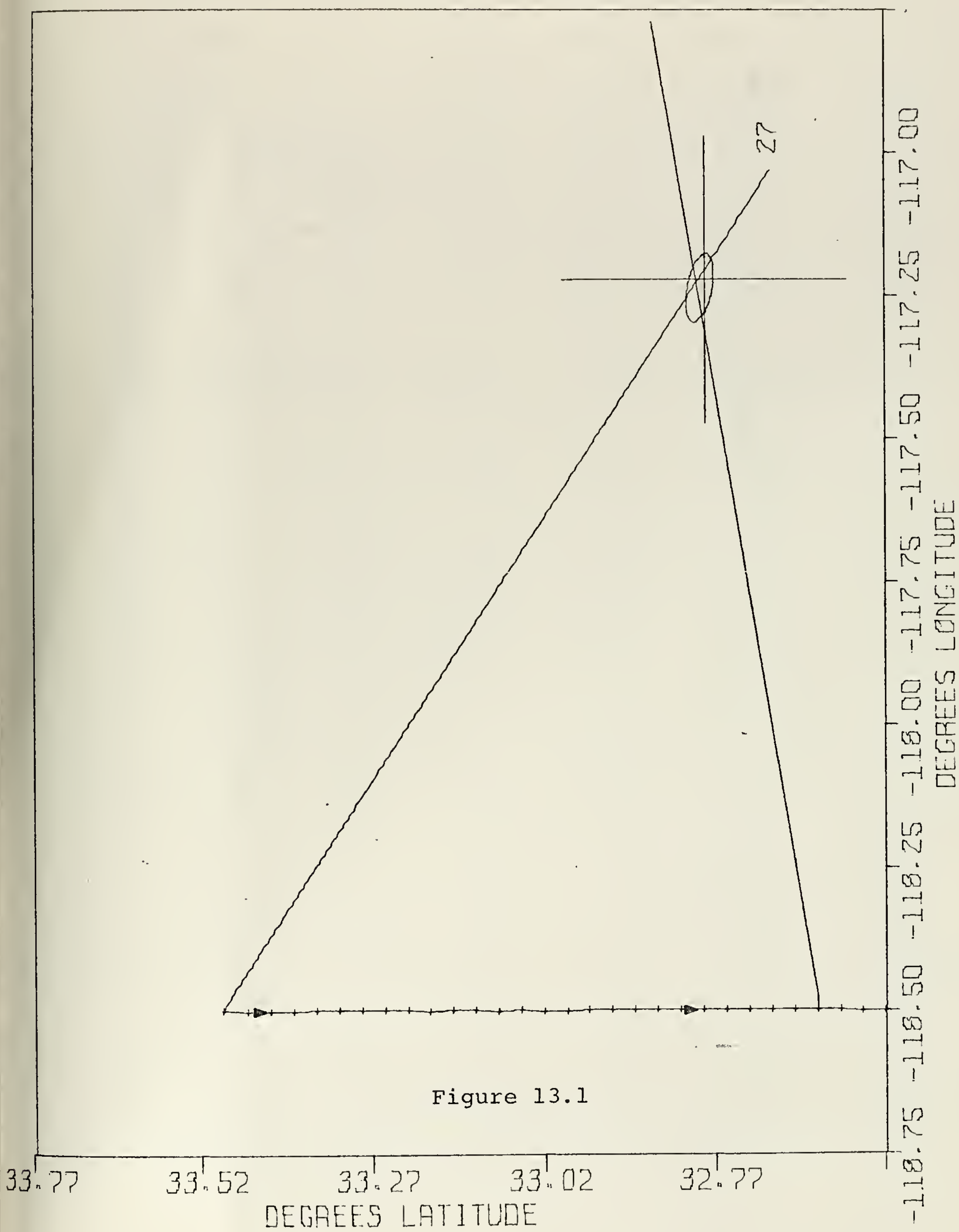


Figure 13.1

PLOT OF ERROR COVARIANCES OF SMOOTHED BEARING LINES

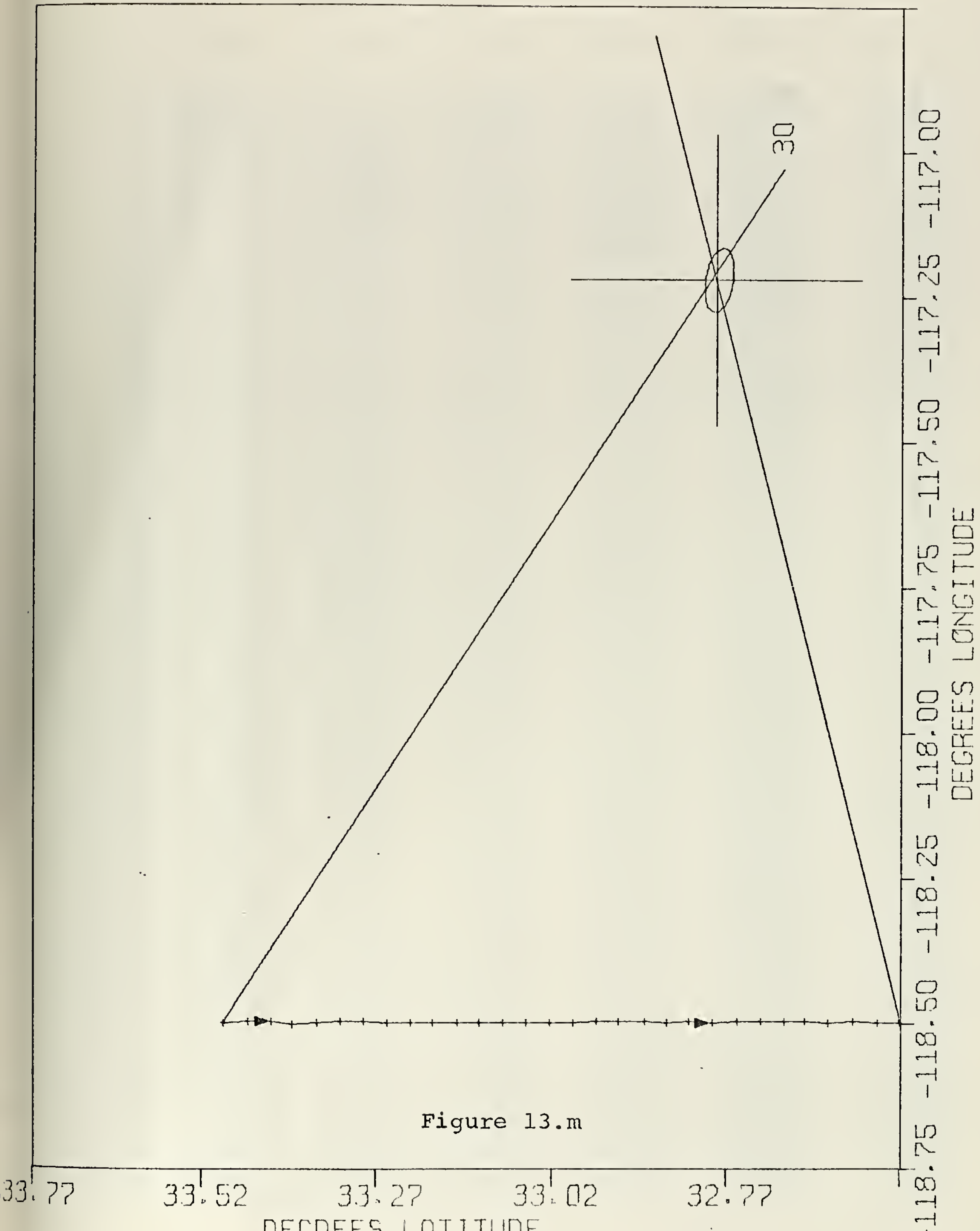


Figure 13.m

```
                  NAVIGATION DATA FILTER PARAMETERS

 K     SG1         SG2         SP11        SP12        SP22         T

 1  0.0         0.0          1.00000    0.0         1.00000       0.0
 2  0.99999     0.16216    37.00000    6.00000     1.00004       6.00
 3  0.99957     0.16646     0.97585    0.16251     0.02711       6.00
 4  0.89002     0.11174     0.00337    0.00042     0.00009       6.00
 5  0.86395     0.10864     0.00265    0.00033     0.00008       6.00
 6  0.86253     0.10906     0.00261    0.00033     0.00008       6.00
 7  0.86251     0.10903     0.00261    0.00033     0.00008       6.00
 8  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
 9  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
10  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
11  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
12  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
13  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
14  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
15  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
16  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
17  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
18  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
19  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
20  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
21  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
22  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
23  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
24  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
25  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
26  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
27  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
28  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
29  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
30  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
31  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
32  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
33  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
34  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
35  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
36  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
37  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
38  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
39  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
40  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
41  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
42  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
43  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
44  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
45  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
46  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
47  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
48  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
49  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
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54  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
55  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
56  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
57  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
58  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
59  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
60  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
61  0.86246     0.10901     0.00261    0.00033     0.00008       6.00
```

```
          NAVIGATION DATA FILTER PARAMETERS

 K   VELND       ELAT          SLATD    VELED      ELON       SLOND


 1 -0.00225  0.0        33.49908  0.00003  0.0      -118.50040
 2 -0.00225  0.0        33.48558  0.00003  0.00003  -118.50020
 3 -0.00316 -0.00546    33.47208 -0.00001 -0.00023  -118.49998
 4 -0.00290  0.00235    33.44765  0.00000  0.00011  -118.50024
 5 -0.00282  0.00075    33.43234 -0.00012 -0.00132  -118.50011
 6 -0.00288 -0.00063    33.41608  0.00012  0.00239  -118.50192
 7 -0.00273  0.00140    33.39821 -0.00010 -0.00224  -118.49911
 8 -0.00256  0.00162    33.38303 -0.00016 -0.00080  -118.50165
 9 -0.00284 -0.00266    33.36908  0.00015  0.00310  -118.50328
10 -0.00279  0.00052    33.34970  0.00010 -0.00029  -118.49971
11 -0.00284 -0.00050    33.33340  0.00014  0.00061  -118.49936
12 -0.00270  0.00134    33.31590 -0.00008 -0.00213  -118.49799
13 -0.00279 -0.00089    33.30086 -0.00005  0.00014  -118.50029
14 -0.00273  0.00055    33.28333  0.00006  0.00114  -118.50047
15 -0.00291 -0.00160    33.26740 -0.00012 -0.00185  -118.49911
16 -0.00278  0.00113    33.24855  0.00003  0.00139  -118.50140
17 -0.00275  0.00032    33.23280  0.00014  0.00130  -118.50003
18 -0.00278 -0.00029    33.21657 -0.00006 -0.00195  -118.49805
19 -0.00281 -0.00031    33.19962 -0.00001  0.00046  -118.50008
20 -0.00256  0.00233    33.18245 -0.00010 -0.00103  -118.49973
21 -0.00298 -0.00383    33.16908 -0.00002  0.00068  -118.50121
22 -0.00276  0.00197    33.14790  0.00001  0.00036  -118.50075
23 -0.00260  0.00153    33.13301  0.00009  0.00082  -118.50034
24 -0.00277 -0.00163    33.11874 -0.00004 -0.00128  -118.49910
25 -0.00294 -0.00154    33.10068  0.00001  0.00049  -118.50046
26 -0.00262  0.00294    33.08167 -0.00008 -0.00093  -118.49998
27 -0.00280 -0.00165    33.06847  0.00002  0.00095  -118.50125
28 -0.00278  0.00017    33.05022  0.00004  0.00031  -118.50031
29 -0.00280 -0.00018    33.03365  0.00003 -0.00012  -118.49976
30 -0.00274  0.00058    33.01665 -0.00011 -0.00142  -118.49968
31 -0.00275 -0.00006    33.00069 -0.00005  0.00049  -118.50154
32 -0.00282 -0.00072    32.98415  0.00000  0.00044  -118.50137
33 -0.00279  0.00035    32.96657  0.00008  0.00088  -118.50098
34 -0.00277  0.00015    32.95013  0.00014  0.00074  -118.49971
35 -0.00274  0.00024    32.93364 -0.00002 -0.00152  -118.49825
36 -0.00272  0.00024    32.91737  0.00001  0.00033  -118.49969
37 -0.00295 -0.00212    32.90126 -0.00005 -0.00065  -118.49934
38 -0.00280  0.00133    32.88174  0.00002  0.00073  -118.50020
39 -0.00260  0.00186    32.86606 -0.00018 -0.00223  -118.49940
40 -0.00280 -0.00186    32.85205  0.00008  0.00256  -118.50243
41 -0.00277  0.00031    32.83360  0.00007  0.00003  -118.49973
42 -0.00274  0.00024    32.81725  0.00005 -0.00012  -118.49927
43 -0.00277 -0.00027    32.80098 -0.00008 -0.00135  -118.49907
44 -0.00285 -0.00067    32.78409 -0.00002  0.00058  -118.50072
45 -0.00299 -0.00130    32.76642 -0.00000  0.00014  -118.50031
46 -0.00265  0.00305    32.74736  0.00005  0.00051  -118.50018
47 -0.00270 -0.00040    32.73405 -0.00002 -0.00063  -118.49947
48 -0.00282 -0.00116    32.71751  0.00011  0.00141  -118.50011
49 -0.00277  0.00047    32.69955 -0.00007 -0.00178  -118.49820
50 -0.00290 -0.00119    32.68330 -0.00000  0.00059  -118.50012
51 -0.00271  0.00172    32.66484  0.00004  0.00044  -118.49962
52 -0.00266  0.00050    32.65002 -0.00003 -0.00071  -118.49901
53 -0.00287 -0.00189    32.63449 -0.00016 -0.00139  -118.49980
54 -0.00270  0.00150    32.61566  0.00008  0.00233  -118.50192
55 -0.00295 -0.00229    32.60072  0.00005 -0.00023  -118.49940
56 -0.00260  0.00323    32.58102 -0.00003 -0.00081  -118.49931
57 -0.00283 -0.00212    32.56819 -0.00011 -0.00089  -118.50020
58 -0.00285 -0.00015    32.54936 -0.00001  0.00090  -118.50162
59 -0.00263  0.00200    32.53214  0.00006  0.00075  -118.50089
60 -0.00278 -0.00134    32.51805 -0.00007 -0.00127  -118.49986
61 -0.00268  0.00092    32.50023  0.00007  0.00133  -118.50134
```

```
        KALMAN FILTER PARAMETERS FOR ANGLE FILTER

I    J    K        P11(K)             P12(K)           G1(K)        G2(K)

1    0    1      10000.0000            0.0             0.9999       0.0
1    2    3    1440001.0000       120000.0000          1.0000       0.0833
1    3    5          6.8125            0.3202          0.8720       0.0410
1    4    7          2.7990            0.1196          0.7368       0.0315
2    0    2      10000.0000            0.0             0.9999       0.0
2    2    4    1440001.0000       120000.0000          1.0000       0.0833
2    3    6          6.8125            0.3202          0.8720       0.0410
2    4    8          2.7990            0.1196          0.7368       0.0315
```

```
        KALMAN FILTER PARAMETERS FOR ANGLE FILTER


I    J    K    T(K)      THTD(K)     TDTD(K)     E(K)        GATE(K)

1    0    1     0.0      106.6854     0.0930
1    2    3    12.000    104.1513    -0.2112    -3.6504    3600.0022
1    3    5    12.000    102.3046    -0.1789     0.7882       8.3853
1    4    7    12.000    100.2979    -0.1729     0.1896       5.8473
2    0    2     0.0      123.1348     0.0810
2    2    4    12.000    122.4821    -0.0544    -1.6245    3600.0022
2    3    6    12.000    120.9605    -0.0952    -0.9966       8.3853
2    4    8    12.000    118.2154    -0.1637    -2.1748       5.8473
```

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THE EXTENDED KALMAN FILTER IS INITIATED WITH THE
FOLLOWING ELLIPSE FOR CUT NUMBER  4 OF TARGET  1

THE ANGLE BETWEEN THE MAJOR AXIS AND THE MERIDIAN
THROUGH THE CENTER OF THE ELLIPSE IS 104.941 DEGREES.

THE LENGTH OF THE SEMI-MAJOR AXIS IS   0.255 DEGREES.

THE LENGTH OF THE SEMI-MINOR AXIS IS   0.019 DEGREES.
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EXTENDED KALMAN FILTER PARAMETERS

```
 K        P11          P12          P22        GX       GY

 7  0.607E-01 -0.161E-01  0.466E-02    0.112   -0.038
 9  0.600E-01 -0.159E-01  0.463E-02    0.162   -0.052
11  0.587E-01 -0.154E-01  0.452E-02    0.213   -0.066
13  0.563E-01 -0.147E-01  0.433E-02    0.247   -0.075
15  0.530E-01 -0.137E-01  0.407E-02    0.271   -0.081
17  0.490E-01 -0.125E-01  0.374E-02    0.283   -0.084
19  0.445E-01 -0.112E-01  0.338E-02    0.282   -0.083
21  0.400E-01 -0.984E-02  0.303E-02    0.278   -0.081
23  0.355E-01 -0.854E-02  0.268E-02    0.265   -0.077
25  0.315E-01 -0.736E-02  0.237E-02    0.250   -0.073
27  0.279E-01 -0.631E-02  0.211E-02    0.233   -0.068
29  0.248E-01 -0.541E-02  0.188E-02    0.217   -0.063
31  0.221E-01 -0.462E-02  0.169E-02    0.201   -0.058
33  0.197E-01 -0.396E-02  0.153E-02    0.186   -0.054
35  0.178E-01 -0.339E-02  0.141E-02    0.172   -0.050
37  0.161E-01 -0.291E-02  0.130E-02    0.159   -0.046
39  0.147E-01 -0.250E-02  0.122E-02    0.147   -0.042
41  0.134E-01 -0.215E-02  0.116E-02    0.137   -0.040
43  0.124E-01 -0.185E-02  0.111E-02    0.128   -0.037
45  0.115E-01 -0.159E-02  0.107E-02    0.119   -0.034
47  0.107E-01 -0.136E-02  0.104E-02    0.112   -0.032
49  0.100E-01 -0.116E-02  0.102E-02    0.104   -0.030
51  0.945E-02 -0.991E-03  0.100E-02    0.098   -0.029
53  0.893E-02 -0.840E-03  0.995E-03    0.092   -0.027
55  0.848E-02 -0.706E-03  0.992E-03    0.087   -0.026
57  0.808E-02 -0.587E-03  0.992E-03    0.082   -0.024
59  0.772E-02 -0.480E-03  0.997E-03    0.077   -0.023
61  0.740E-02 -0.384E-03  0.100E-02    0.073   -0.022
```

```
 K     DMX       DMY        TX        ER          XTD         YTD

 7  -0.1794   -1.0314   1.7552   -0.0038   -117.4961    33.2432
 9  -0.1434   -1.0706   1.7169    0.0115   -117.4918    33.2473
11  -0.1003   -1.1082   1.6731   -0.0015   -117.4896    33.2476
13  -0.0614   -1.1383   1.6329   -0.0041   -117.4890    33.2481
15  -0.0214   -1.1676   1.5921    0.0299   -117.4888    33.2486
17   0.0184   -1.1950   1.5552   -0.0279   -117.4849    33.2477
19   0.0551   -1.2111   1.5116    0.0199   -117.4873    33.2489
21   0.0952   -1.2323   1.4762    0.0289   -117.4850    33.2484
23   0.1308   -1.2440   1.4402    0.0189   -117.4816    33.2476
25   0.1648   -1.2498   1.4021    0.0047   -117.4790    33.2469
27   0.1974   -1.2532   1.3639    0.0028   -117.4777    33.2466
29   0.2293   -1.2548   1.3271    0.0192   -117.4768    33.2464
31   0.2591   -1.2524   1.2935    0.0172   -117.4747    33.2457
33   0.2868   -1.2474   1.2585    0.0295   -117.4728    33.2451
35   0.3120   -1.2394   1.2264    0.0241   -117.4701    33.2442
37   0.3348   -1.2271   1.1930   -0.0068   -117.4678    33.2433
39   0.3544   -1.2130   1.1593   -0.0061   -117.4673    33.2431
41   0.3747   -1.1995   1.1279   -0.0027   -117.4671    33.2429
43   0.3928   -1.1829   1.0972    0.0181   -117.4668    33.2427
45   0.4092   -1.1646   1.0686    0.0406   -117.4657    33.2422
47   0.4227   -1.1455   1.0422    0.0241   -117.4636    33.2413
49   0.4340   -1.1243   1.0137    0.0142   -117.4621    33.2407
51   0.4436   -1.1032   0.9872   -0.0088   -117.4610    33.2401
53   0.4516   -1.0810   0.9607    0.0099   -117.4609    33.2399
55   0.4596   -1.0589   0.9365   -0.0008   -117.4602    33.2395
57   0.4651   -1.0360   0.9123    0.0172   -117.4599    33.2393
59   0.4702   -1.0137   0.8903    0.0351   -117.4592    33.2389
61   0.4738   -0.9917   0.8696    0.0168   -117.4580    33.2383
```

EXTENDED KALMAN FILTER PARAMETERS

```
 K     EP11          EP12          EP22          G1       G2

 7  0.607E-01  -0.161E-01   0.466E-02     0.548   -0.145
 9  0.239E-01   0.668E-02   0.236E-02     0.323    0.090
11  0.134E 00   0.151E-01   0.179E-02     0.728    0.082
13  0.106E 00   0.745E-02   0.594E-03     0.679    0.048
15  0.712E-01   0.382E-02   0.273E-03     0.587    0.031
17  0.538E-01   0.249E-02   0.189E-03     0.518    0.024
19  0.450E-01   0.198E-02   0.165E-03     0.474    0.021
21  0.406E-01   0.179E-02   0.160E-03     0.448    0.020
23  0.387E-01   0.173E-02   0.161E-03     0.437    0.020
25  0.381E-01   0.174E-02   0.163E-03     0.433    0.020
27  0.381E-01   0.176E-02   0.165E-03     0.433    0.020
29  0.383E-01   0.178E-02   0.166E-03     0.434    0.020
31  0.384E-01   0.178E-02   0.166E-03     0.435    0.020
33  0.385E-01   0.179E-02   0.166E-03     0.435    0.020
35  0.385E-01   0.179E-02   0.166E-03     0.435    0.020
37  0.385E-01   0.179E-02   0.166E-03     0.435    0.020
39  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
41  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
43  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
45  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
47  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
49  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
51  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
53  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
55  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
57  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
59  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
61  0.385E-01   0.179E-02   0.165E-03     0.435    0.020
```

```
 K      EX         EY       XTDDOT    YTDDOT       XTD1        YTD1

 7   0.0        0.0        0.0010    0.0010   -117.4965    33.2434
 9  -0.0054    -0.0059     0.0004    0.0005   -117.4899    33.2467
11  -0.0006    -0.0034     0.0003    0.0002   -117.4899    33.2477
13  -0.0019    -0.0011     0.0002    0.0001   -117.4900    33.2484
15  -0.0018    -0.0005     0.0001    0.0001   -117.4807    33.2462
17   0.0062    -0.0032     0.0002    0.0000   -117.4928    33.2500
19  -0.0077     0.0021     0.0000    0.0001   -117.4816    33.2472
21   0.0045    -0.0022     0.0001    0.0000   -117.4769    33.2461
23   0.0062    -0.0026     0.0002   -0.0000   -117.4765    33.2461
25   0.0032    -0.0014     0.0002   -0.0000   -117.4778    33.2465
27  -0.0001    -0.0002     0.0002   -0.0000   -117.4770    33.2464
29  -0.0004     0.0000     0.0001   -0.0000   -117.4726    33.2452
31   0.0028    -0.0010     0.0002   -0.0001   -117.4712    33.2447
33   0.0021    -0.0007     0.0002   -0.0001   -117.4673    33.2435
35   0.0037    -0.0012     0.0002   -0.0001   -117.4659    33.2430
37   0.0024    -0.0006     0.0002   -0.0001   -117.4688    33.2436
39  -0.0020     0.0009     0.0001   -0.0001   -117.4682    33.2433
41  -0.0015     0.0008     0.0001   -0.0001   -117.4674    33.2430
43  -0.0008     0.0005     0.0001   -0.0001   -117.4645    33.2420
45   0.0016    -0.0003     0.0001   -0.0001   -117.4608    33.2408
47   0.0036    -0.0010     0.0001   -0.0001   -117.4609    33.2405
49   0.0016    -0.0003     0.0001   -0.0001   -117.4606    33.2402
51   0.0005     0.0001     0.0001   -0.0001   -117.4619    33.2404
53  -0.0013     0.0008     0.0001   -0.0001   -117.4599    33.2397
55   0.0004     0.0002     0.0001   -0.0001   -117.4603    33.2396
57  -0.0004     0.0004     0.0001   -0.0001   -117.4585    33.2389
59   0.0009    -0.0001     0.0001   -0.0001   -117.4565    33.2381
61   0.0020    -0.0004     0.0001   -0.0001   -117.4568    33.2379
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THE EXTENDED KALMAN FILTER IS INITIATED WITH THE
FOLLOWING ELLIPSE FOR CUT NUMBER  4 OF TARGET  2

THE ANGLE BETWEEN THE MAJOR AXIS AND THE MERIDIAN
THROUGH THE CENTER OF THE ELLIPSE IS 122.129 DEGREES.

THE LENGTH OF THE SEMI-MAJOR AXIS IS   0.361 DEGREES.

THE LENGTH OF THE SEMI-MINOR AXIS IS   0.023 DEGREES.
```

EXTENDED KALMAN FILTER PARAMETERS

K	P11	P12	P22	GX	GY
8	0.934E-01	-0.583E-01	0.371E-01	-0.038	0.015
10	0.933E-01	-0.583E-01	0.372E-01	0.036	-0.032
12	0.932E-01	-0.582E-01	0.371E-01	0.116	-0.083
14	0.925E-01	-0.577E-01	0.368E-01	0.193	-0.132
16	0.906E-01	-0.564E-01	0.360E-01	0.263	-0.176
18	0.870E-01	-0.540E-01	0.344E-01	0.317	-0.209
20	0.816E-01	-0.504E-01	0.320E-01	0.353	-0.232
22	0.747E-01	-0.459E-01	0.291E-01	0.370	-0.242
24	0.669E-01	-0.408E-01	0.259E-01	0.373	-0.242
26	0.589E-01	-0.356E-01	0.225E-01	0.360	-0.233
28	0.513E-01	-0.307E-01	0.194E-01	0.340	-0.219
30	0.445E-01	-0.263E-01	0.166E-01	0.318	-0.204
32	0.386E-01	-0.225E-01	0.142E-01	0.294	-0.189
34	0.335E-01	-0.193E-01	0.121E-01	0.272	-0.174
36	0.292E-01	-0.165E-01	0.104E-01	0.250	-0.160
38	0.256E-01	-0.142E-01	0.894E-02	0.230	-0.146
40	0.225E-01	-0.122E-01	0.774E-02	0.211	-0.134
42	0.199E-01	-0.106E-01	0.673E-02	0.195	-0.124
44	0.177E-01	-0.921E-02	0.589E-02	0.180	-0.114
46	0.159E-01	-0.804E-02	0.518E-02	0.166	-0.105
48	0.143E-01	-0.705E-02	0.459E-02	0.154	-0.097
50	0.130E-01	-0.620E-02	0.410E-02	0.143	-0.090
52	0.118E-01	-0.548E-02	0.368E-02	0.132	-0.083
54	0.109E-01	-0.486E-02	0.332E-02	0.124	-0.078
56	0.100E-01	-0.432E-02	0.302E-02	0.116	-0.073
58	0.925E-02	-0.386E-02	0.276E-02	0.109	-0.068
60	0.860E-02	-0.344E-02	0.254E-02	0.102	-0.064

K	DMX	DMY	TX	ER	XTD	YTD
8	-0.3977	-0.6036	2.0672	-0.0139	-117.4485	32.9048
10	-0.3825	-0.6431	2.0379	0.0056	-117.4464	32.9055
12	-0.3630	-0.6822	2.0063	0.0211	-117.4460	32.9052
14	-0.3428	-0.7220	1.9754	0.0292	-117.4444	32.9038
16	-0.3208	-0.7603	1.9448	0.0314	-117.4413	32.9012
18	-0.2977	-0.7959	1.9146	0.0325	-117.4371	32.8977
20	-0.2727	-0.8287	1.8842	0.0265	-117.4321	32.8935
22	-0.2477	-0.8595	1.8535	0.0498	-117.4273	32.8894
24	-0.2212	-0.8901	1.8263	0.0581	-117.4191	32.8825
26	-0.1952	-0.9131	1.7991	0.0444	-117.4091	32.8741
28	-0.1699	-0.9326	1.7687	0.0505	-117.4005	32.8667
30	-0.1441	-0.9517	1.7412	0.0391	-117.3913	32.8586
32	-0.1187	-0.9690	1.7109	0.0381	-117.3836	32.8515
34	-0.0936	-0.9876	1.6825	0.0519	-117.3765	32.8446
36	-0.0677	-1.0046	1.6555	0.0429	-117.3684	32.8369
38	-0.0433	-1.0175	1.6265	0.0201	-117.3615	32.8299
40	-0.0189	-1.0307	1.5953	0.0517	-117.3570	32.8247
42	0.0066	-1.0461	1.5705	0.0524	-117.3506	32.8180
44	0.0315	-1.0571	1.5415	0.0407	-117.3445	32.8115
46	0.0546	-1.0664	1.5126	0.0369	-117.3394	32.8058
48	0.0782	-1.0757	1.4840	0.0673	-117.3350	32.8005
50	0.1018	-1.0834	1.4587	0.0190	-117.3292	32.7943
52	0.1227	-1.0873	1.4272	-0.0098	-117.3262	32.7901
54	0.1456	-1.0930	1.3954	0.0013	-117.3250	32.7873
56	0.1687	-1.0984	1.3671	0.0506	-117.3237	32.7845
58	0.1908	-1.1013	1.3425	0.0127	-117.3206	32.7805
60	0.2102	-1.1013	1.3124	0.0133	-117.3191	32.7778

```
              EXTENDED KALMAN FILTER PARAMETERS


 K      EP11          EP12          EP22           G1         G2

 8   0.934E-01  -0.583E-01   0.371E-01     0.651    -0.407
10   0.272E 00   0.602E-01   0.135E-01     0.845     0.187
12   0.234E 00   0.225E-01   0.223E-02     0.824     0.079
14   0.105E 00   0.662E-02   0.477E-03     0.677     0.043
16   0.665E-01   0.330E-02   0.230E-03     0.571     0.028
18   0.505E-01   0.224E-02   0.172E-03     0.502     0.022
20   0.429E-01   0.185E-02   0.159E-03     0.462     0.020
22   0.394E-01   0.173E-02   0.158E-03     0.441     0.019
24   0.381E-01   0.171E-02   0.160E-03     0.432     0.019
26   0.379E-01   0.174E-02   0.163E-03     0.431     0.020
28   0.380E-01   0.176E-02   0.165E-03     0.432     0.020
30   0.383E-01   0.178E-02   0.166E-03     0.434     0.020
32   0.384E-01   0.179E-02   0.166E-03     0.435     0.020
34   0.385E-01   0.179E-02   0.166E-03     0.435     0.020
36   0.386E-01   0.179E-02   0.166E-03     0.435     0.020
38   0.385E-01   0.179E-02   0.166E-03     0.435     0.020
40   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
42   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
44   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
46   0.385E-01   0.178E-02   0.165E-03     0.435     0.020
48   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
50   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
52   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
54   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
56   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
58   0.385E-01   0.179E-02   0.165E-03     0.435     0.020
60   0.385E-01   0.179E-02   0.165E-03     0.435     0.020


 K       EX          EY       XTDDOT    YTDDOT       XTD1         YTD1

 8    0.0         0.0         0.0010    0.0010   -117.4480     32.9046
10   -0.0046     -0.0062      0.0001   -0.0002   -117.4462     32.9053
12   -0.0004      0.0008      0.0001   -0.0001   -117.4436     32.9034
14    0.0017     -0.0012      0.0001   -0.0001   -117.4388     32.8999
16    0.0041     -0.0030      0.0002   -0.0002   -117.4331     32.8957
18    0.0059     -0.0041      0.0003   -0.0003   -117.4268     32.8909
20    0.0072     -0.0049      0.0004   -0.0004   -117.4228     32.8874
22    0.0061     -0.0036      0.0004   -0.0005   -117.4089     32.8773
24    0.0135     -0.0091      0.0006   -0.0007   -117.3974     32.8684
26    0.0154     -0.0101      0.0007   -0.0009   -117.3931     32.8638
28    0.0098     -0.0051      0.0008   -0.0010   -117.3834     32.8556
30    0.0105     -0.0053      0.0008   -0.0011   -117.3789     32.8506
32    0.0063     -0.0015      0.0008   -0.0011   -117.3724     32.8443
34    0.0054     -0.0006      0.0008   -0.0011   -117.3624     32.8356
36    0.0080     -0.0023      0.0008   -0.0012   -117.3577     32.8300
38    0.0051      0.0001      0.0007   -0.0012   -117.3569     32.8270
40    0.0002      0.0040      0.0006   -0.0011   -117.3461     32.8177
42    0.0060     -0.0005      0.0006   -0.0011   -117.3404     32.8115
44    0.0054      0.0001      0.0006   -0.0011   -117.3372     32.8068
46    0.0030      0.0019      0.0006   -0.0011   -117.3333     32.8019
48    0.0023      0.0024      0.0005   -0.0010   -117.3247     32.7940
50    0.0061     -0.0005      0.0005   -0.0010   -117.3265     32.7926
52   -0.0004      0.0044      0.0004   -0.0009   -117.3275     32.7909
54   -0.0033      0.0064      0.0003   -0.0008   -117.3248     32.7872
56   -0.0015      0.0047      0.0002   -0.0007   -117.3178     32.7809
58    0.0037      0.0005      0.0003   -0.0007   -117.3192     32.7797
60   -0.0002      0.0033      0.0002   -0.0006   -117.3177     32.7770
```

```
                      TARGET NUMBER   1

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER   1

  K   FREQ    PRF    PW     THETAD      THTD       SLAD       SLOD

  1 1197.0 150.0 3.50   106.6854  106.6854   33.4991 -118.5004
  3 1197.0 150.0 3.50   104.1513  104.1513   33.4670 -118.5002
  5 1197.0 150.0 3.50   102.4055  102.3046   33.4326 -118.5007
  7 1197.0 150.0 3.50   100.3478  100.2979   33.4000 -118.5012

  SMOOTHED INITIAL BEARING ANGLE = 106.68600 N

    FILTERED FINAL BEARING ANGLE = 100.29791 W


           VECTOR METHOD SOLUTION OF EMITTER LOCATION

                 EMITTER LATITUDE =  33.24323 N

                EMITTER LONGITUDE =-117.49606 W

      EXTENDED KALMAN FILTER SOLUTION OF EMITTER LOCATION

                 EMITTER LATITUDE =  33.23833 N

                EMITTER LONGITUDE =-117.45799 W
```

```
                        TARGET NUMBER   2

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER   2

  K  FREQ    PRF    PW     THETAD       THTD        SLAD       SLOD

  2 1212.0 250.0 3.00   123.1348   123.1348    33.4856 -118.5002
  4 1212.0 250.0 3.00   122.4821   122.4821    33.4498 -118.5004
  6 1212.0 250.0 3.00   120.8329   120.9605    33.4160 -118.5004
  8 1212.0 250.0 3.00   117.6429   118.2154    33.3836 -118.5015

  SMOOTHED INITIAL BEARING ANGLE = 123.13493 N

    FILTERED FINAL BEARING ANGLE = 118.21536 W


          VECTOR METHOD SOLUTION OF EMITTER LOCATION

                EMITTER LATITUDE =  32.90477 N

               EMITTER LONGITUDE =-117.44853 W

     EXTENDED KALMAN FILTER SOLUTION OF EMITTER LOCATION

                EMITTER LATITUDE =  32.77782 N

               EMITTER LONGITUDE =-117.31906 W
```

* * *

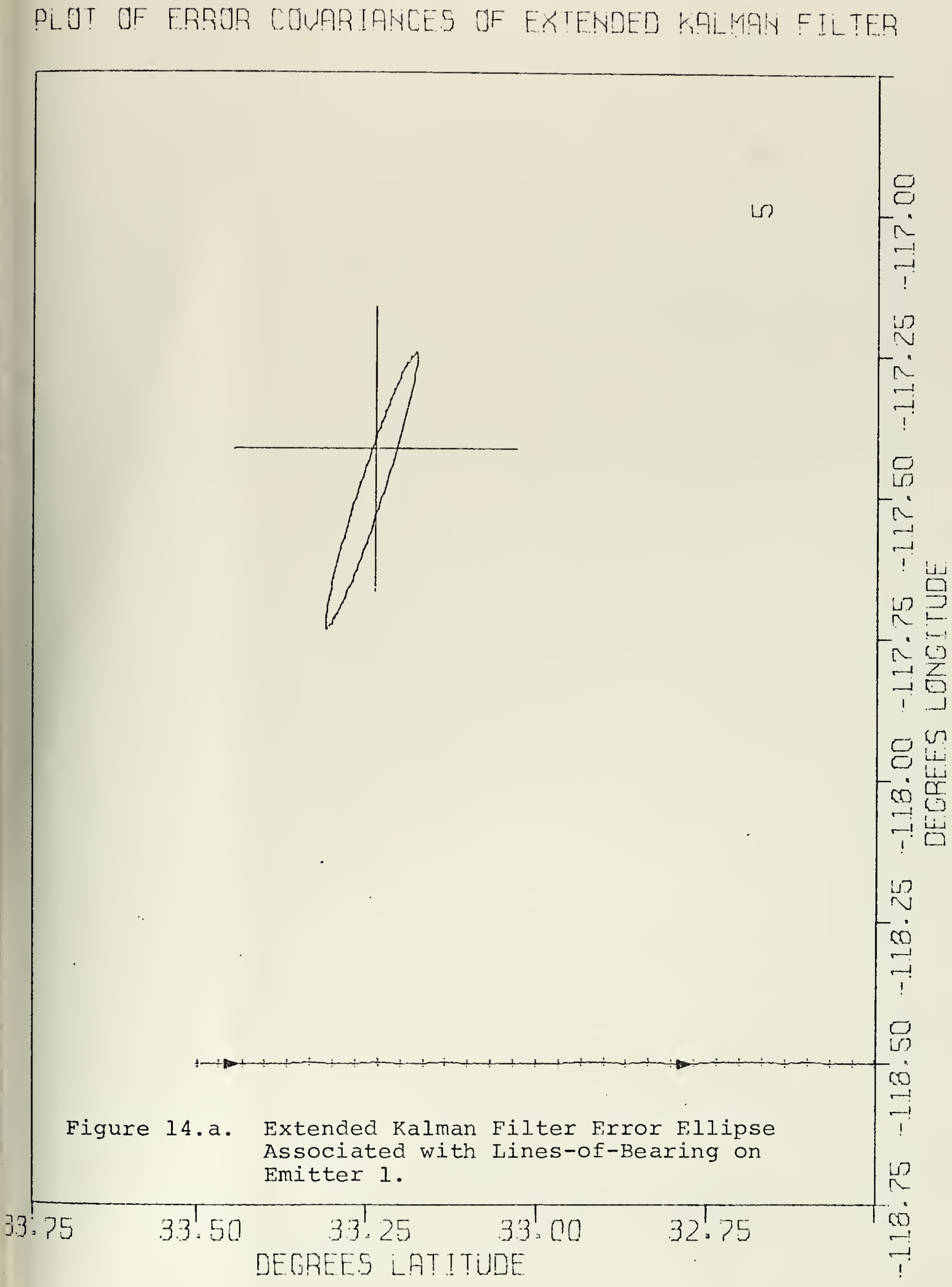

Figure 14.a. Extended Kalman Filter Error Ellipse Associated with Lines-of-Bearing on Emitter 1.

PLØT ØF ERRØR CØVARIANCES ØF EXTENDED KALMAN FILTER

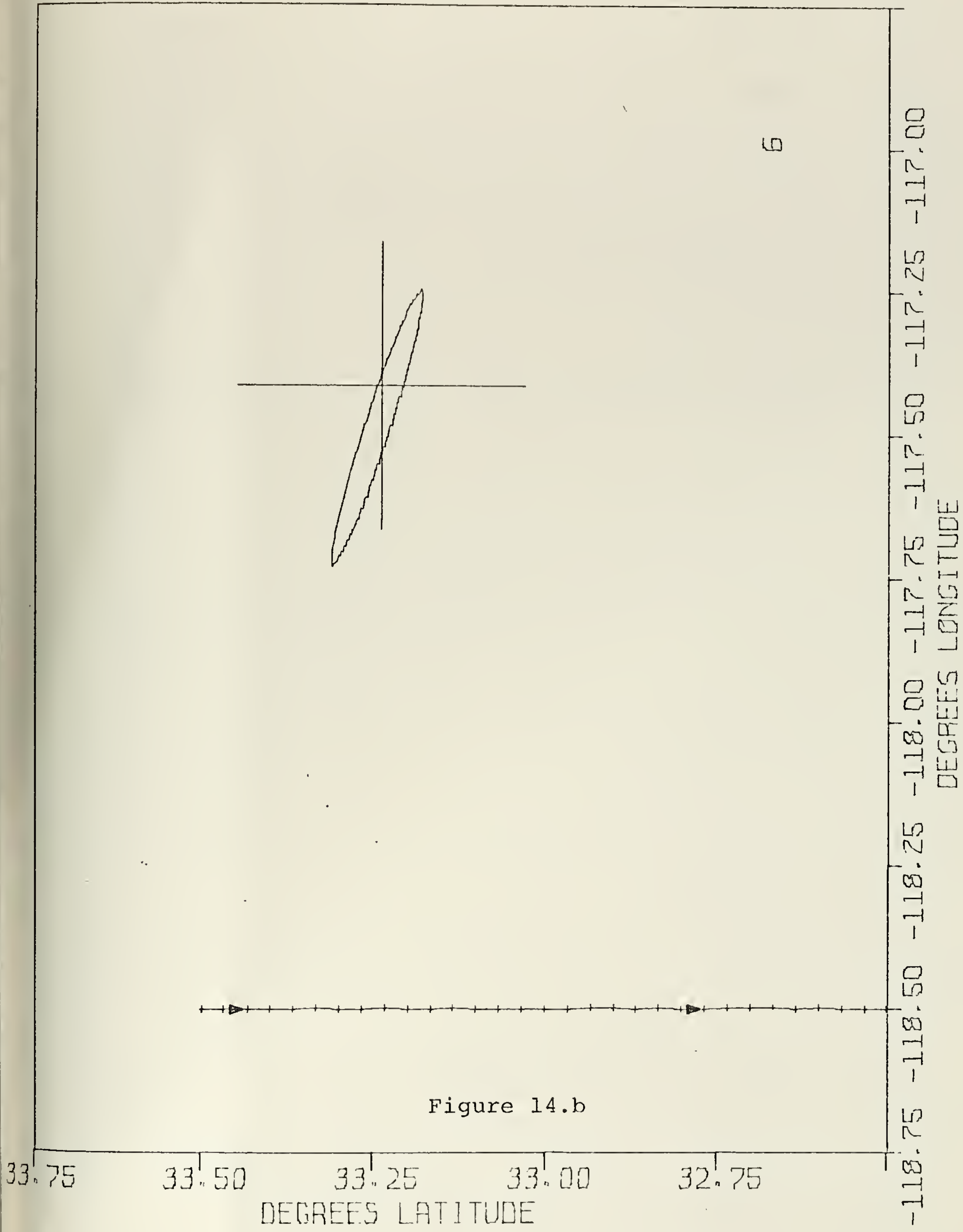

Figure 14.b

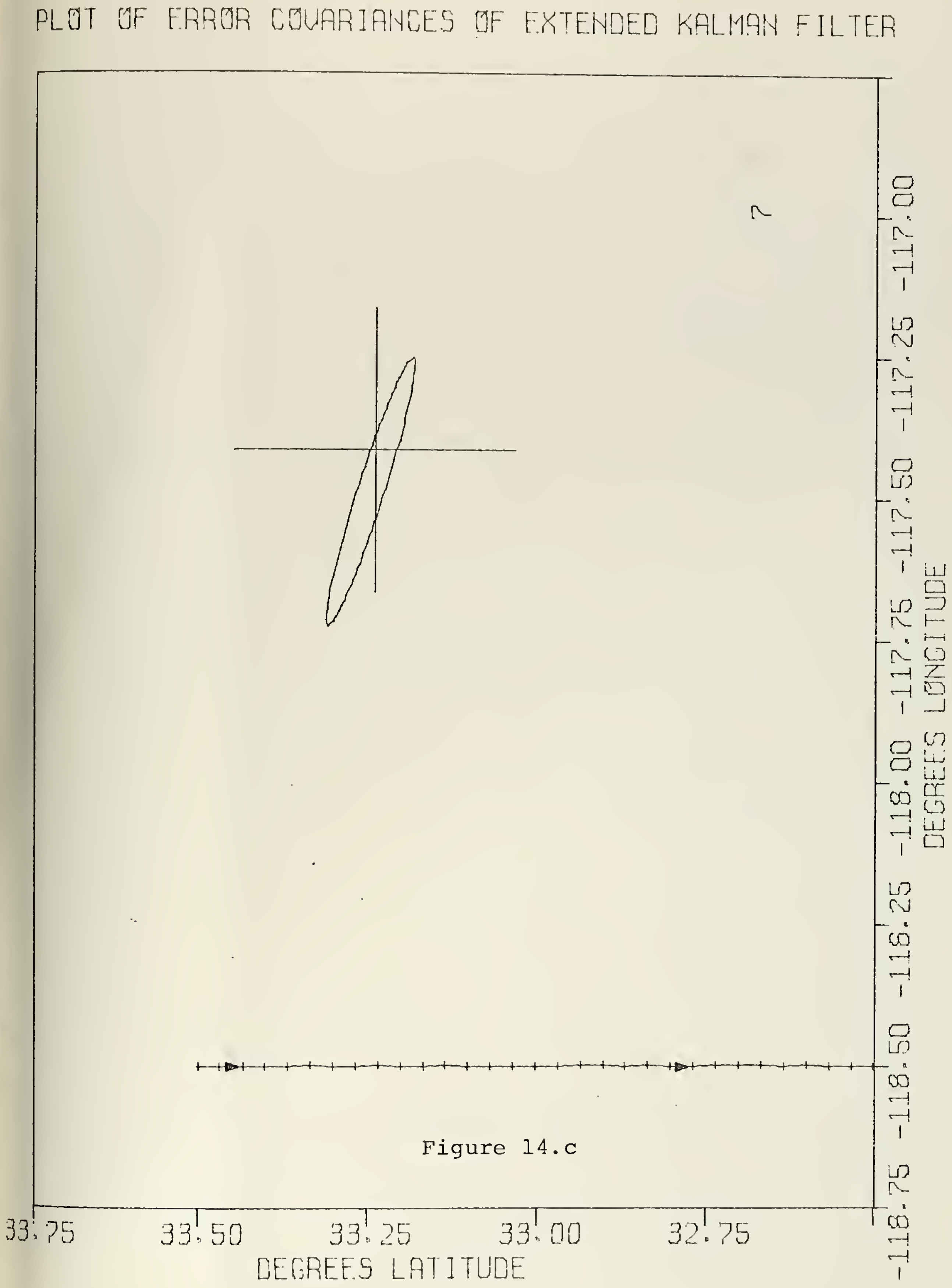
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
7
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 14.c

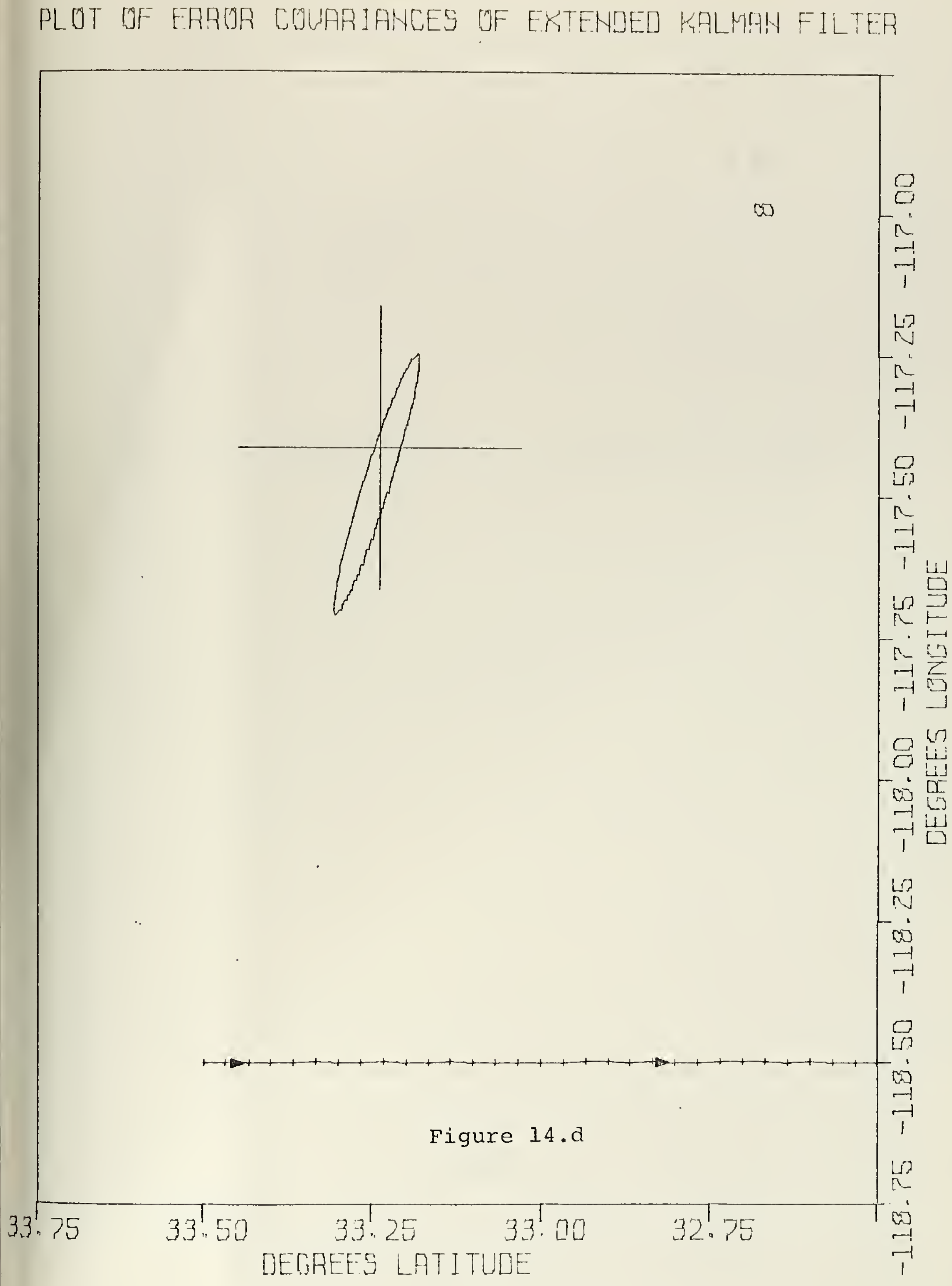
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
8
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE

Figure 14.d

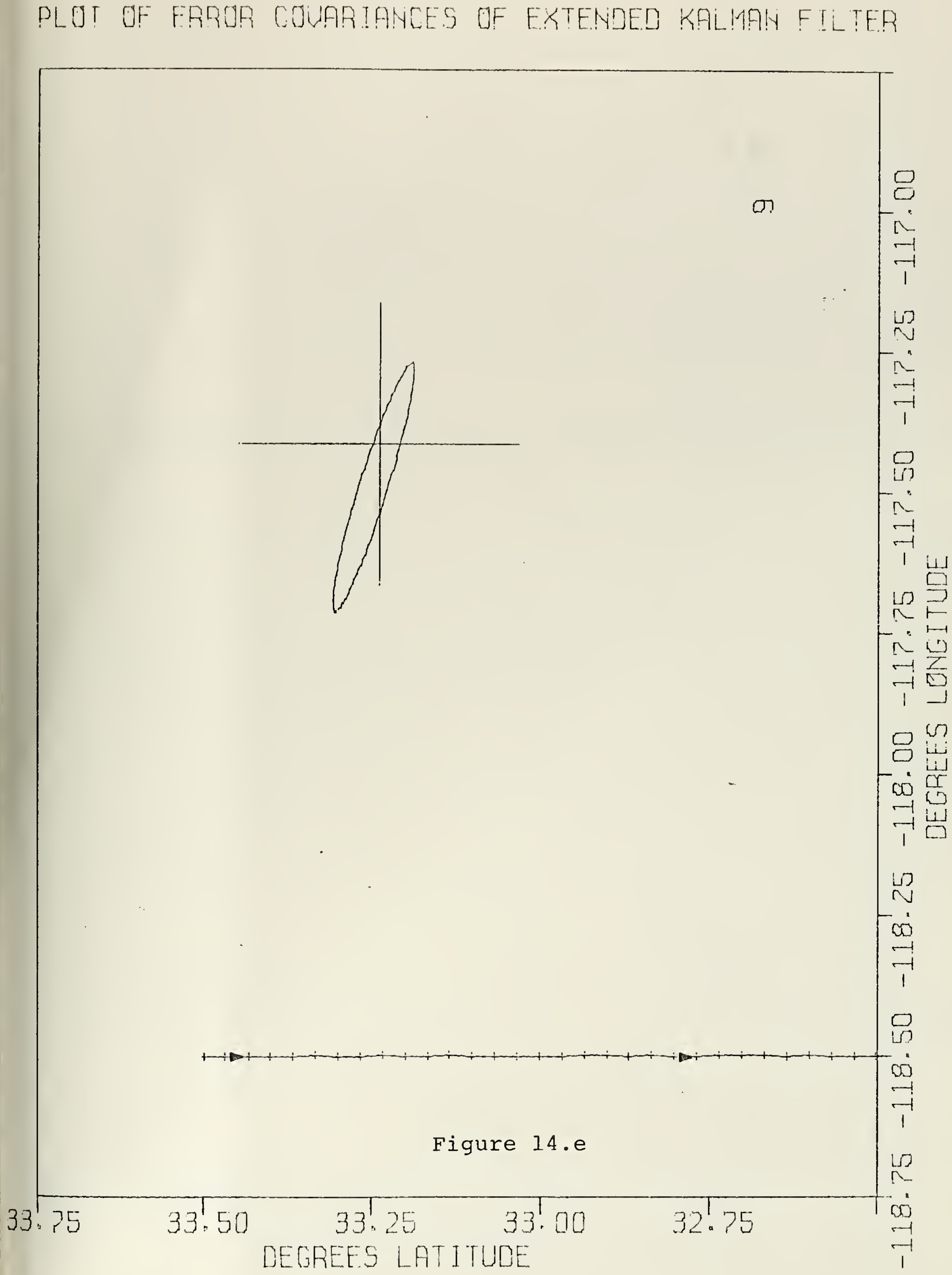
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
9
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 14.e

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

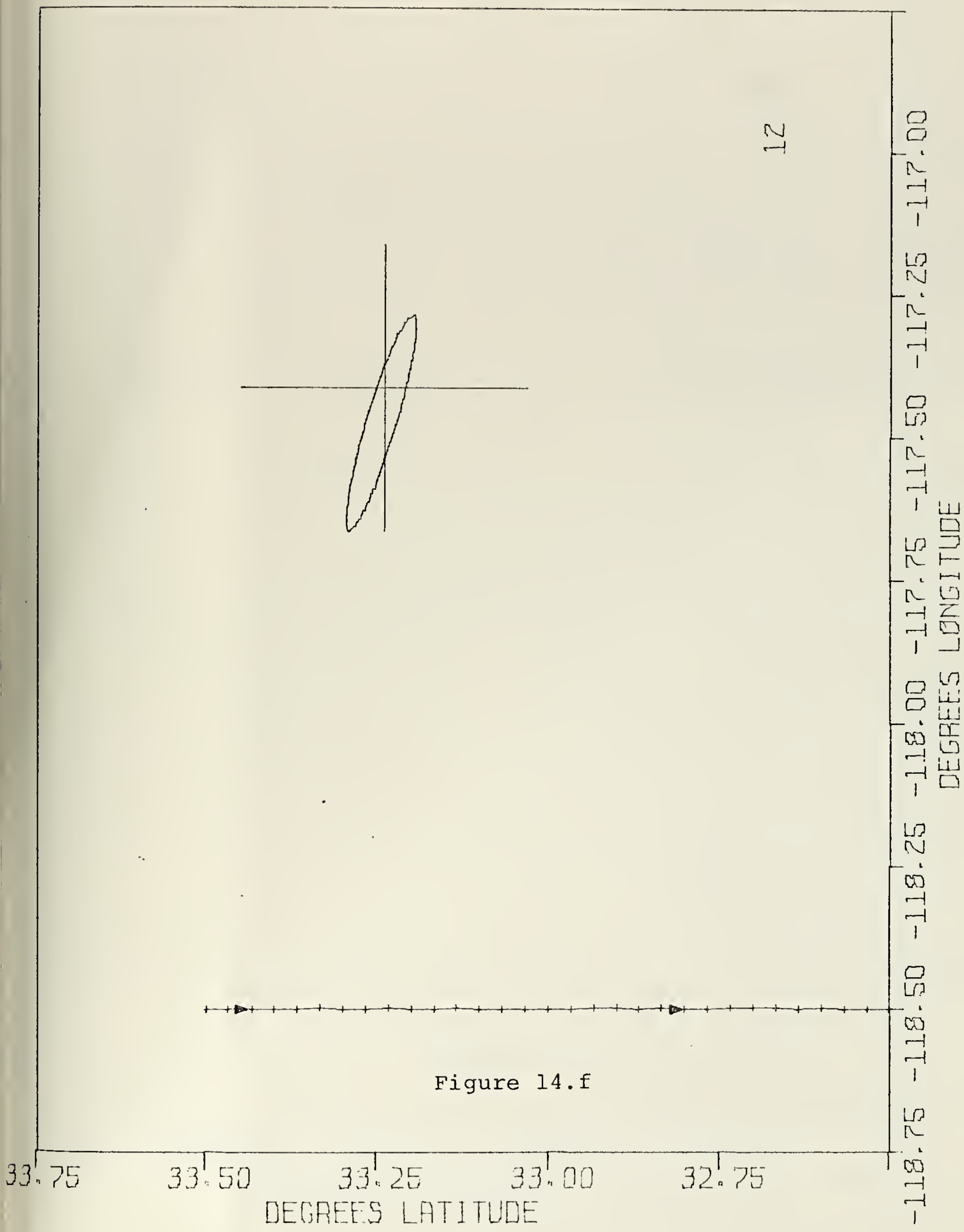

Figure 14.f

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

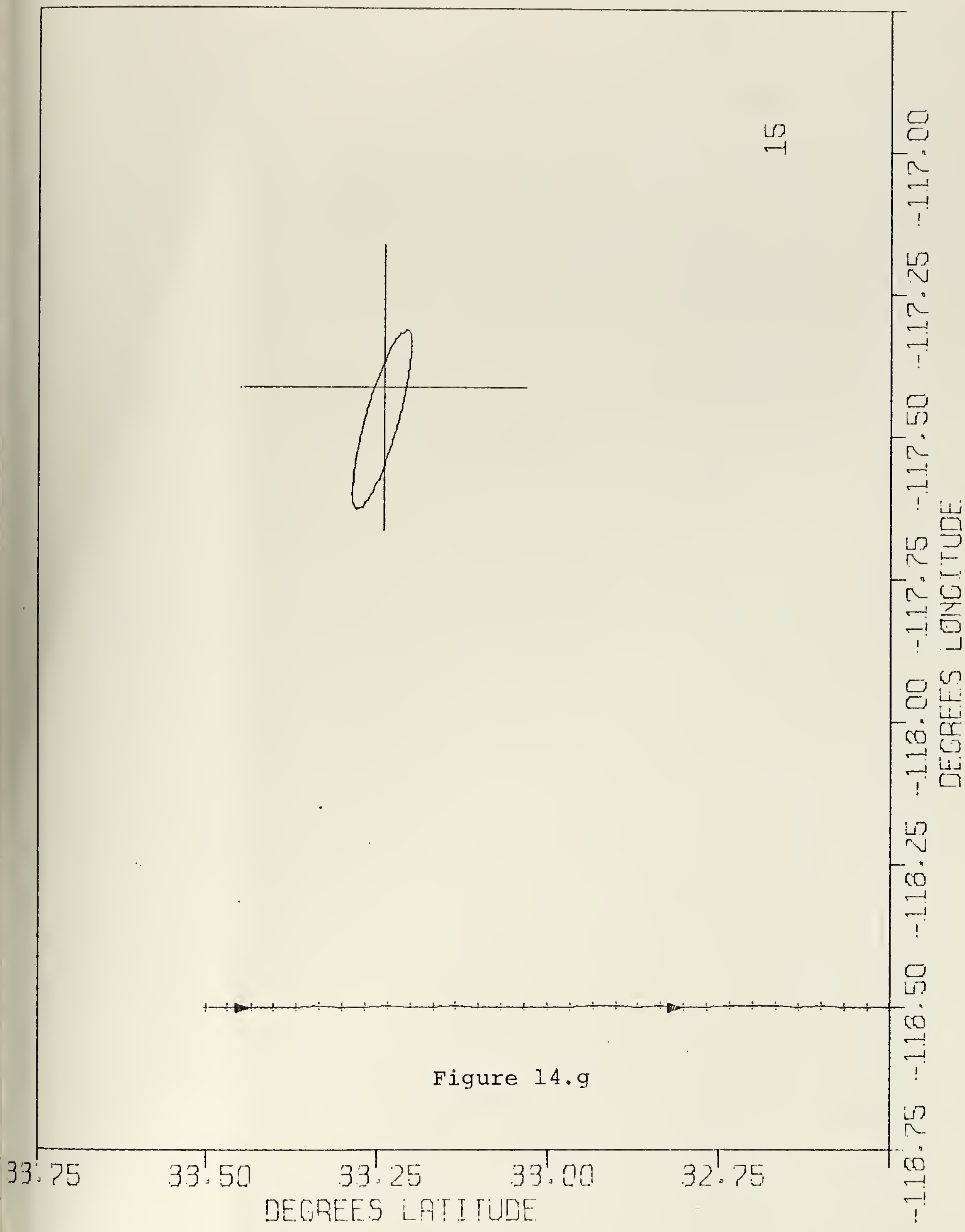

Figure 14.g

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

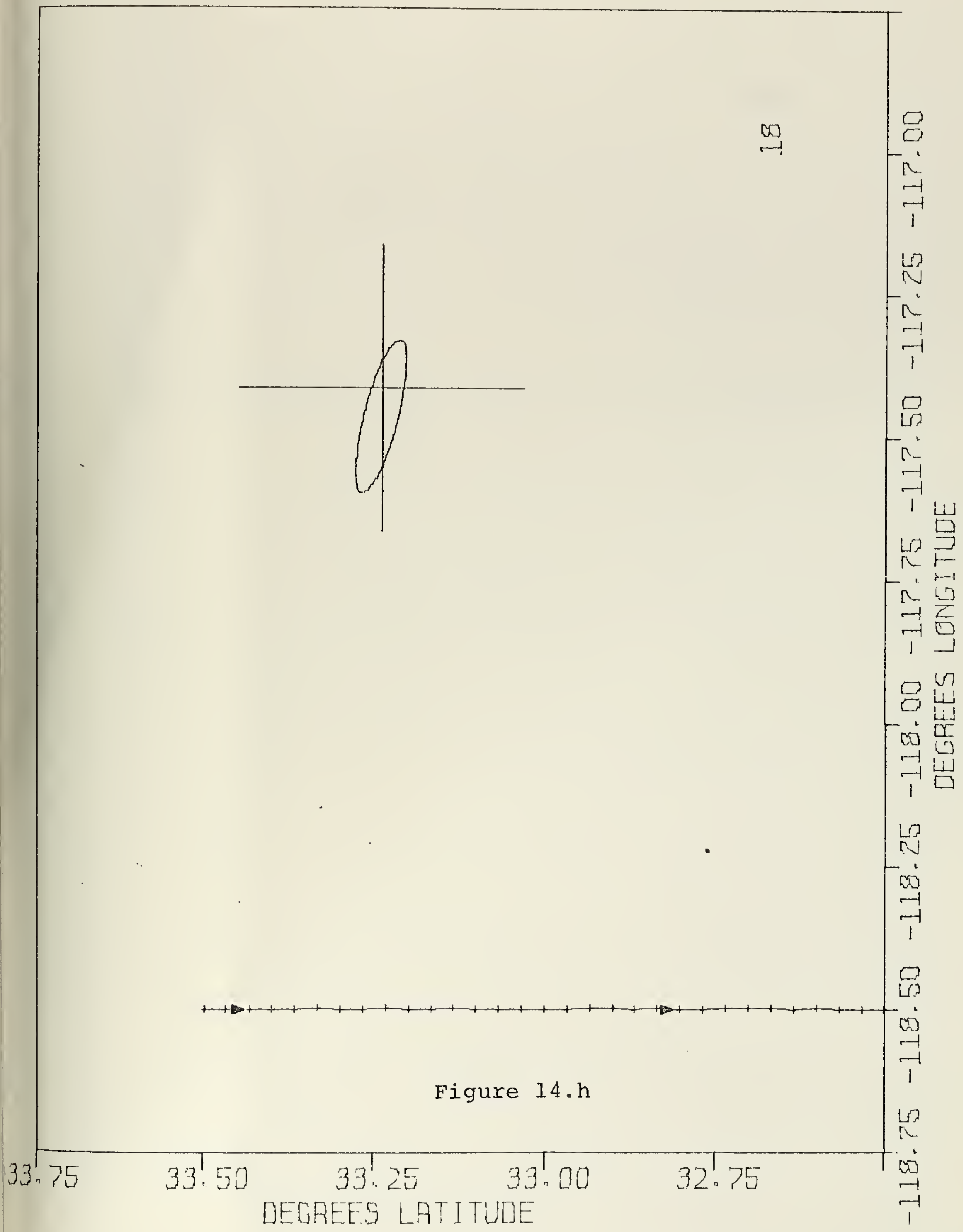

Figure 14.h

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

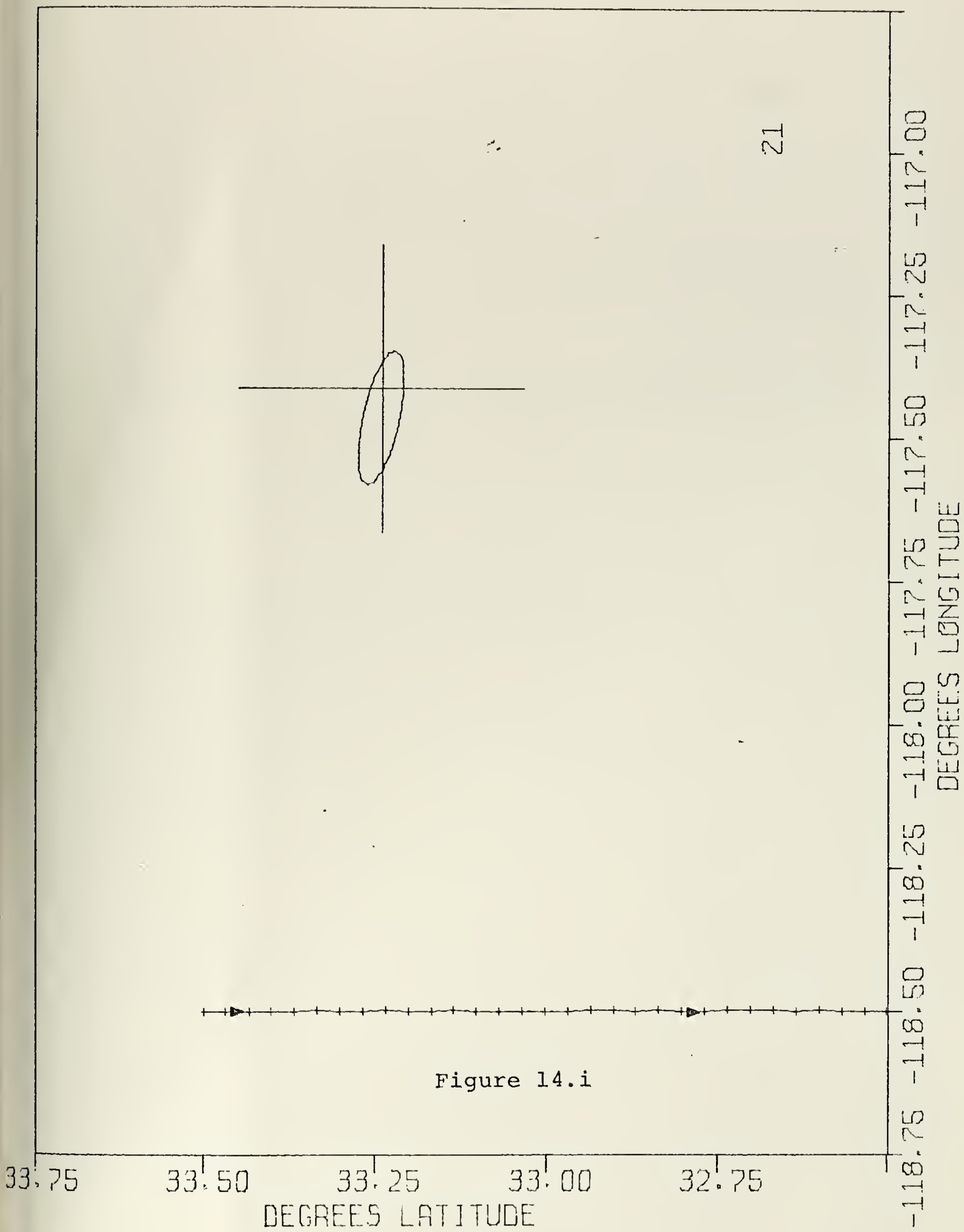

Figure 14.i

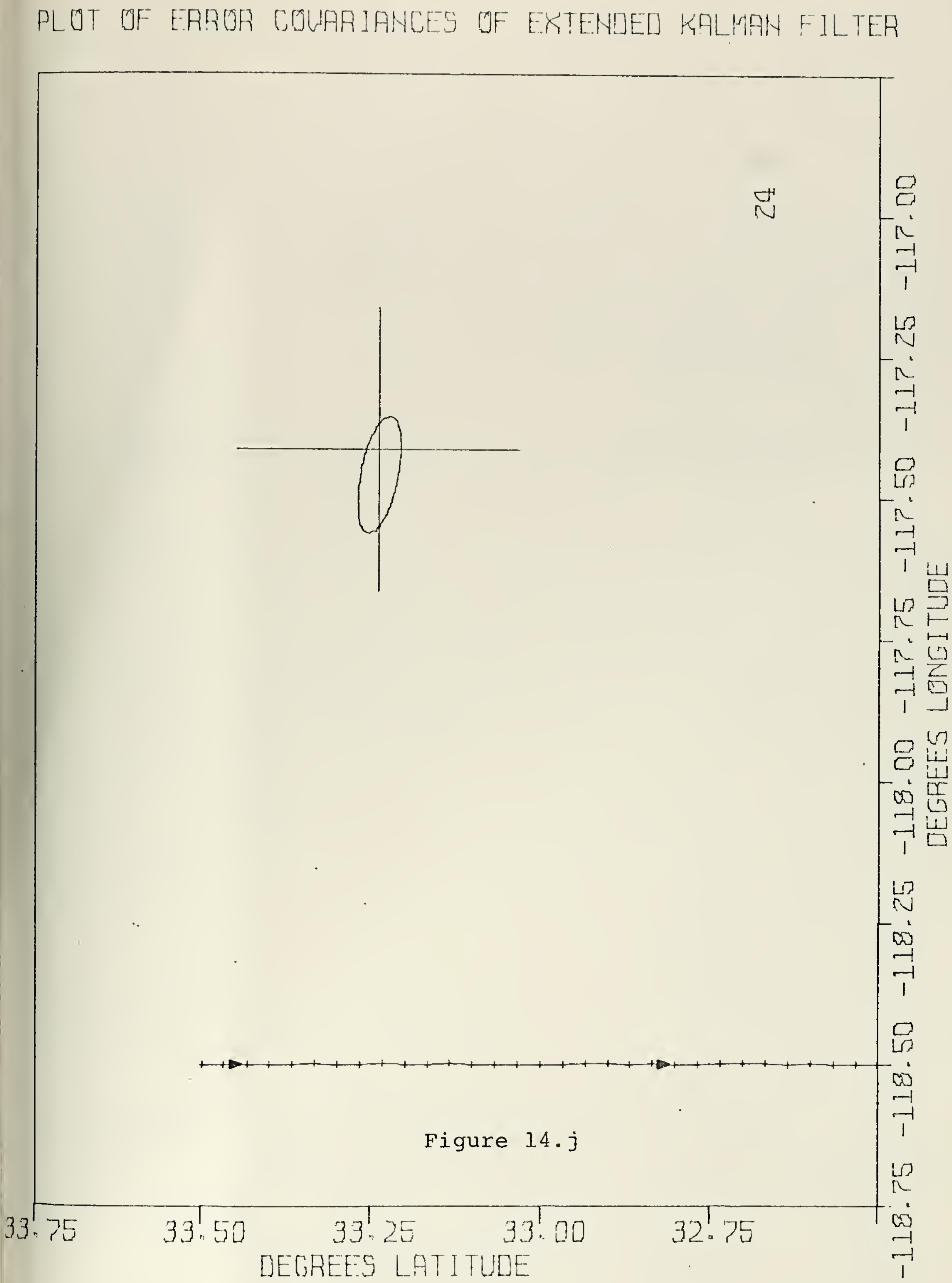
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
24
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 14.j

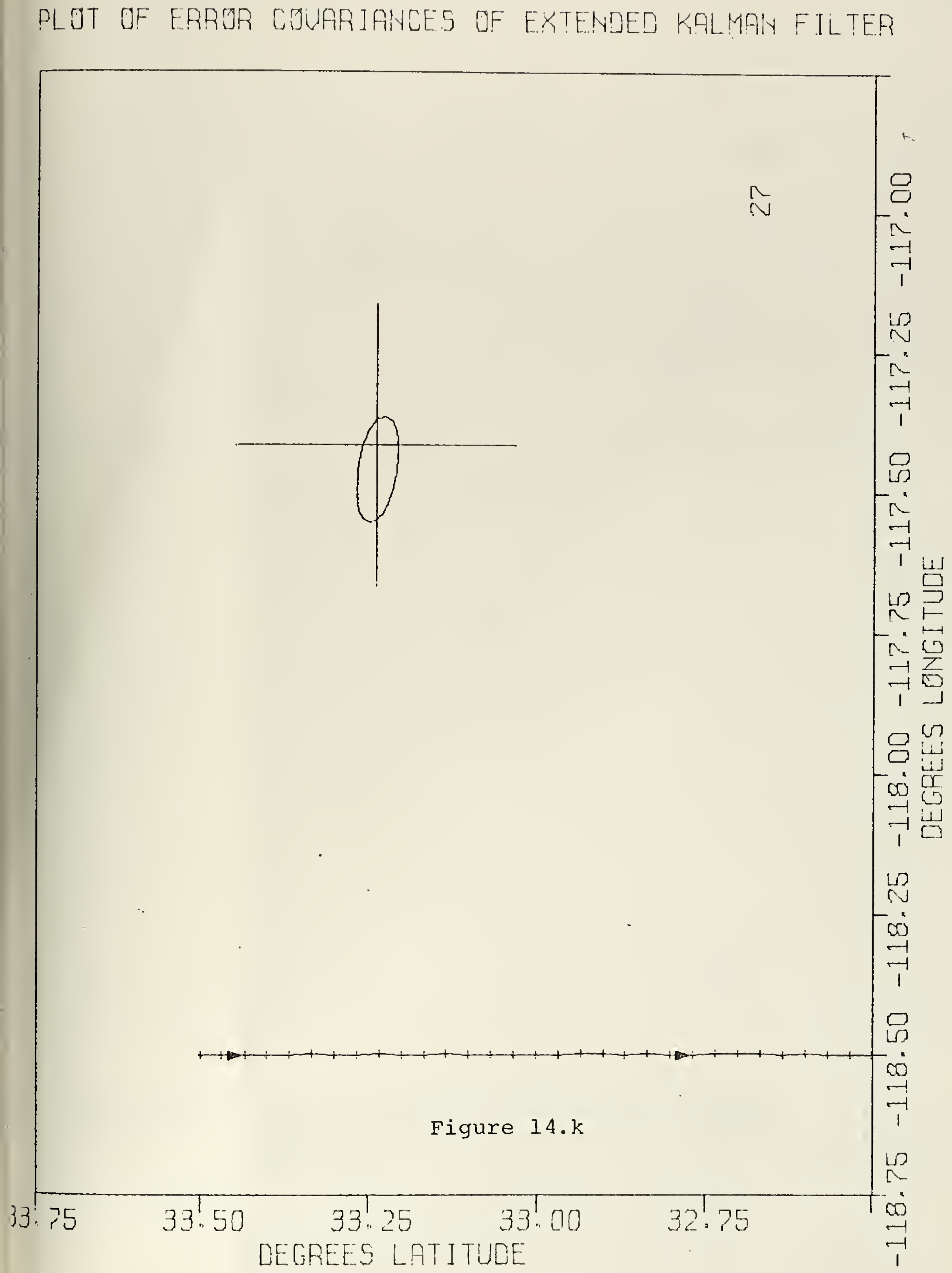
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
27
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
-118.75
DEGREES LONGITUDE
33.75
33.50
33.25
33.00
32.75
DEGREES LATITUDE

Figure 14.k

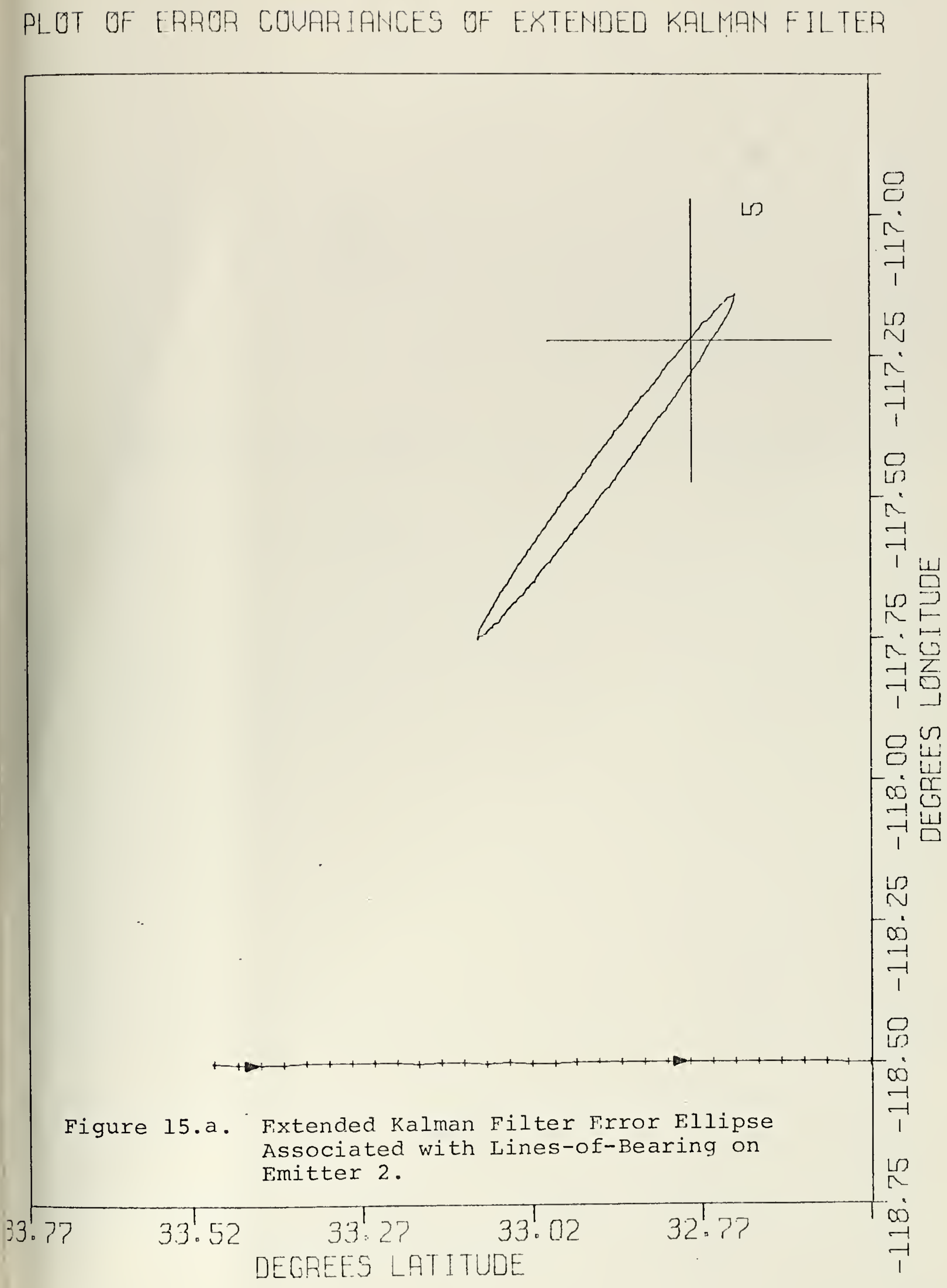

Figure 15.a. Extended Kalman Filter Error Ellipse Associated with Lines-of-Bearing on Emitter 2.

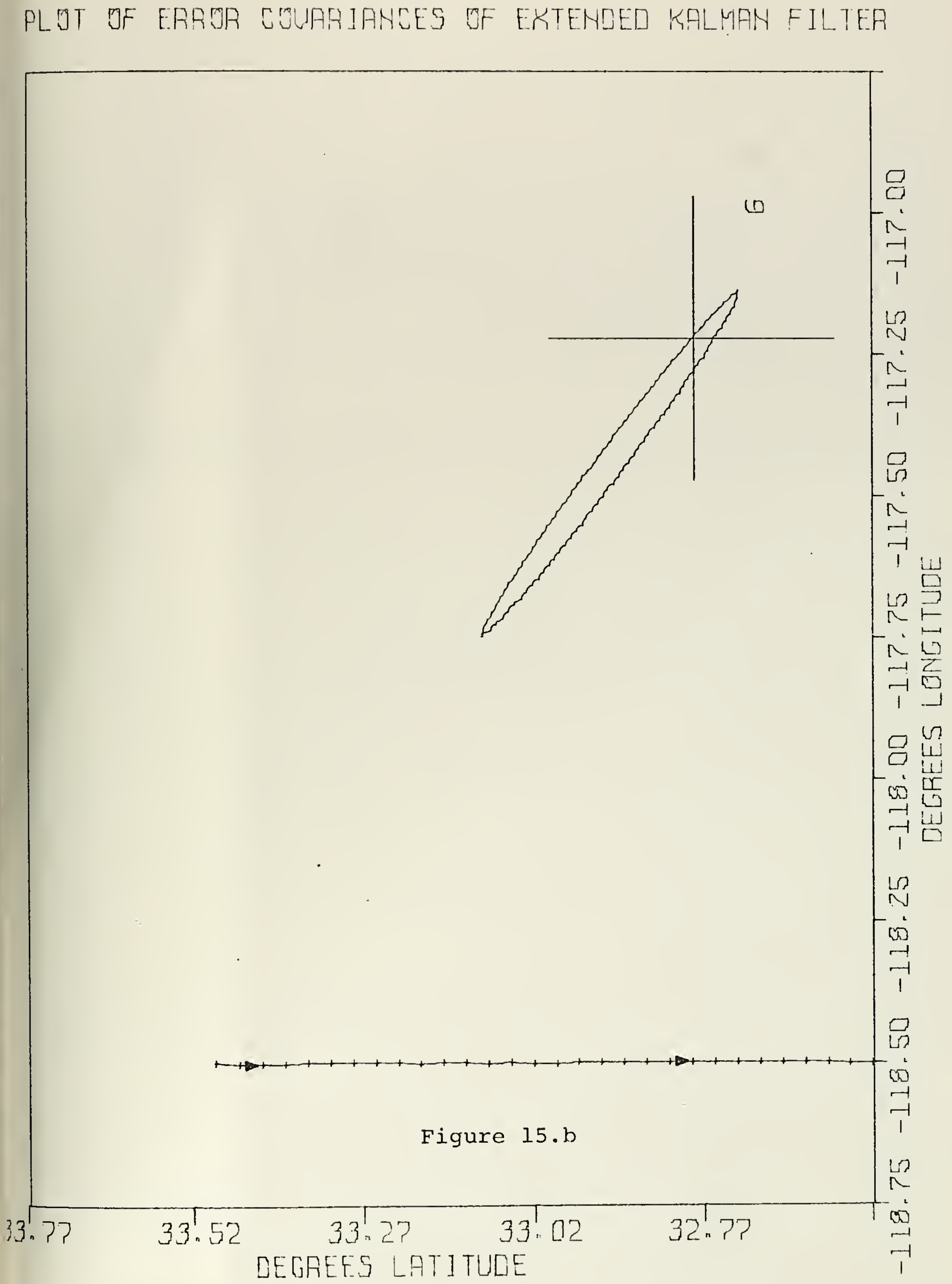
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
6
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE

Figure 15.b

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

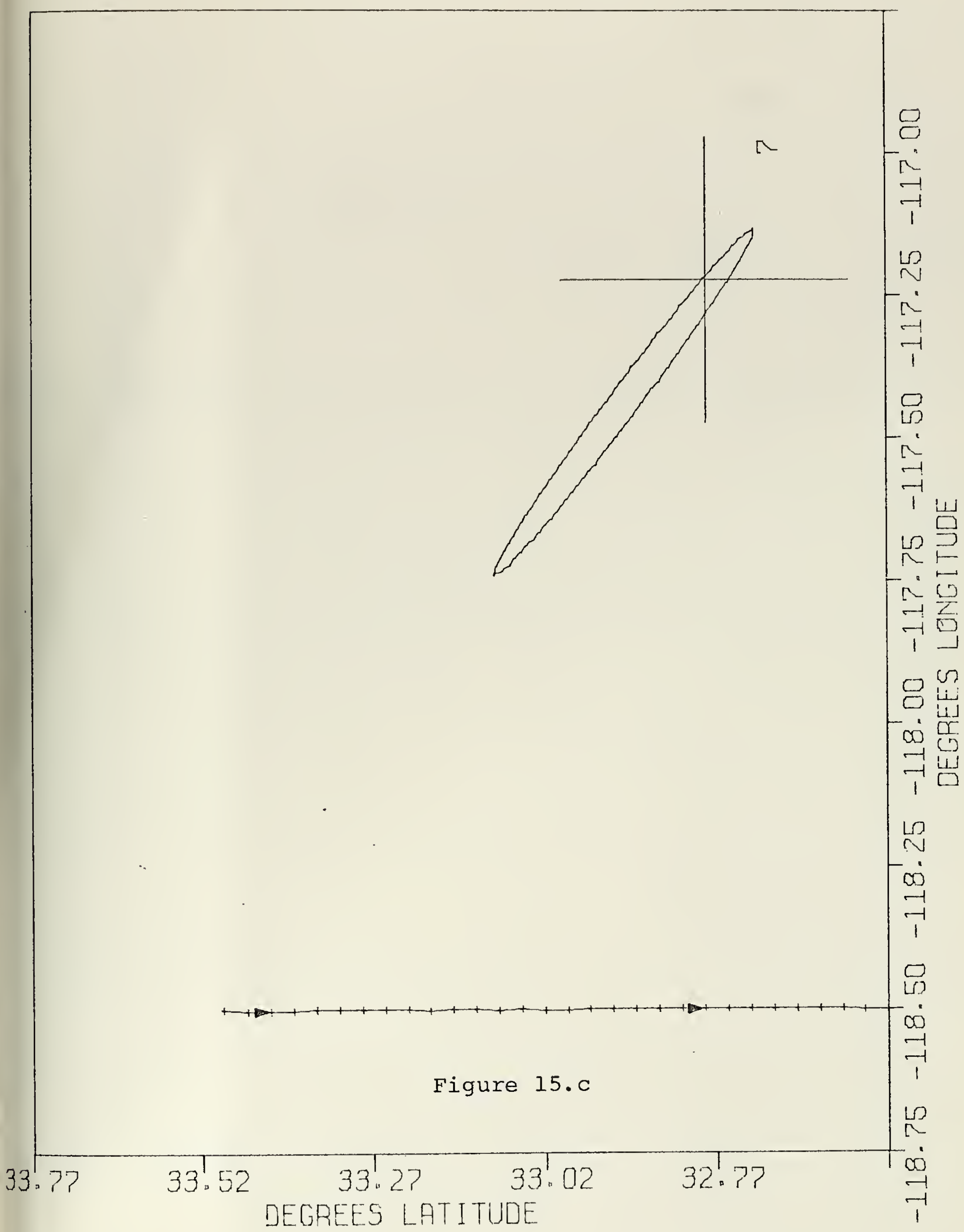

Figure 15.c

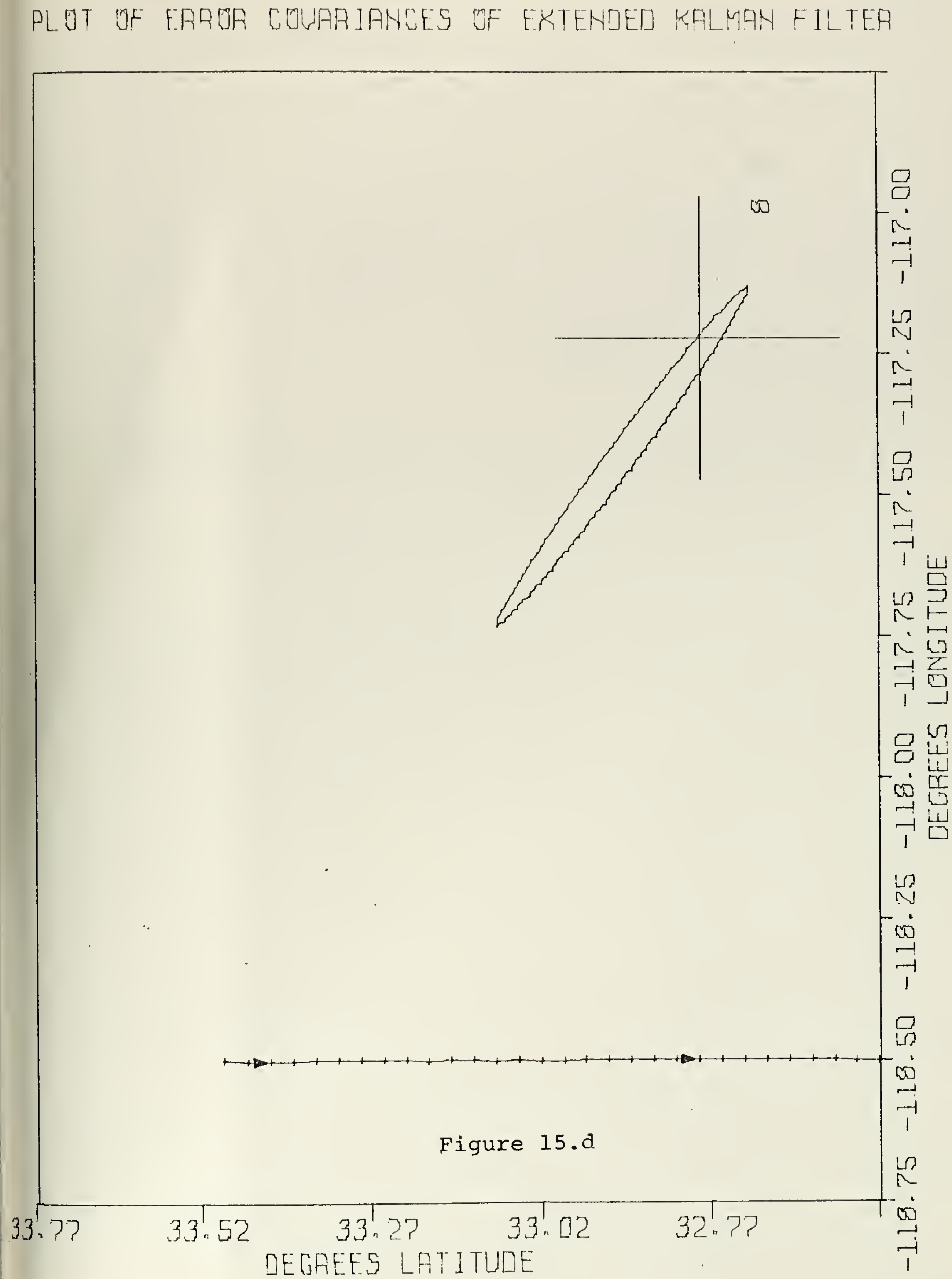
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
8
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE

Figure 15.d

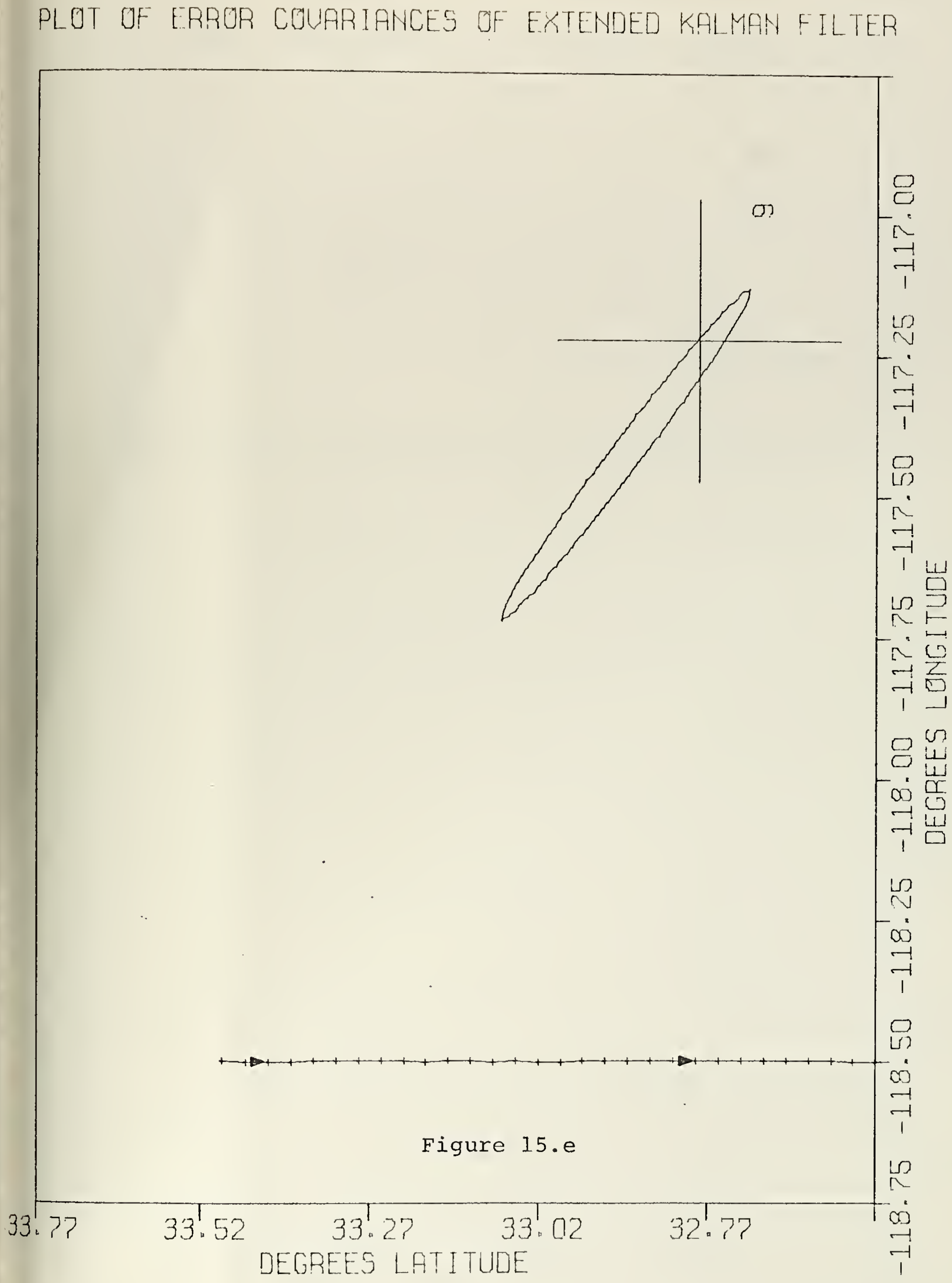
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
9
DEGREES LONGITUDE
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LATITUDE
33.77
33.52
33.27
33.02
32.77

Figure 15.e

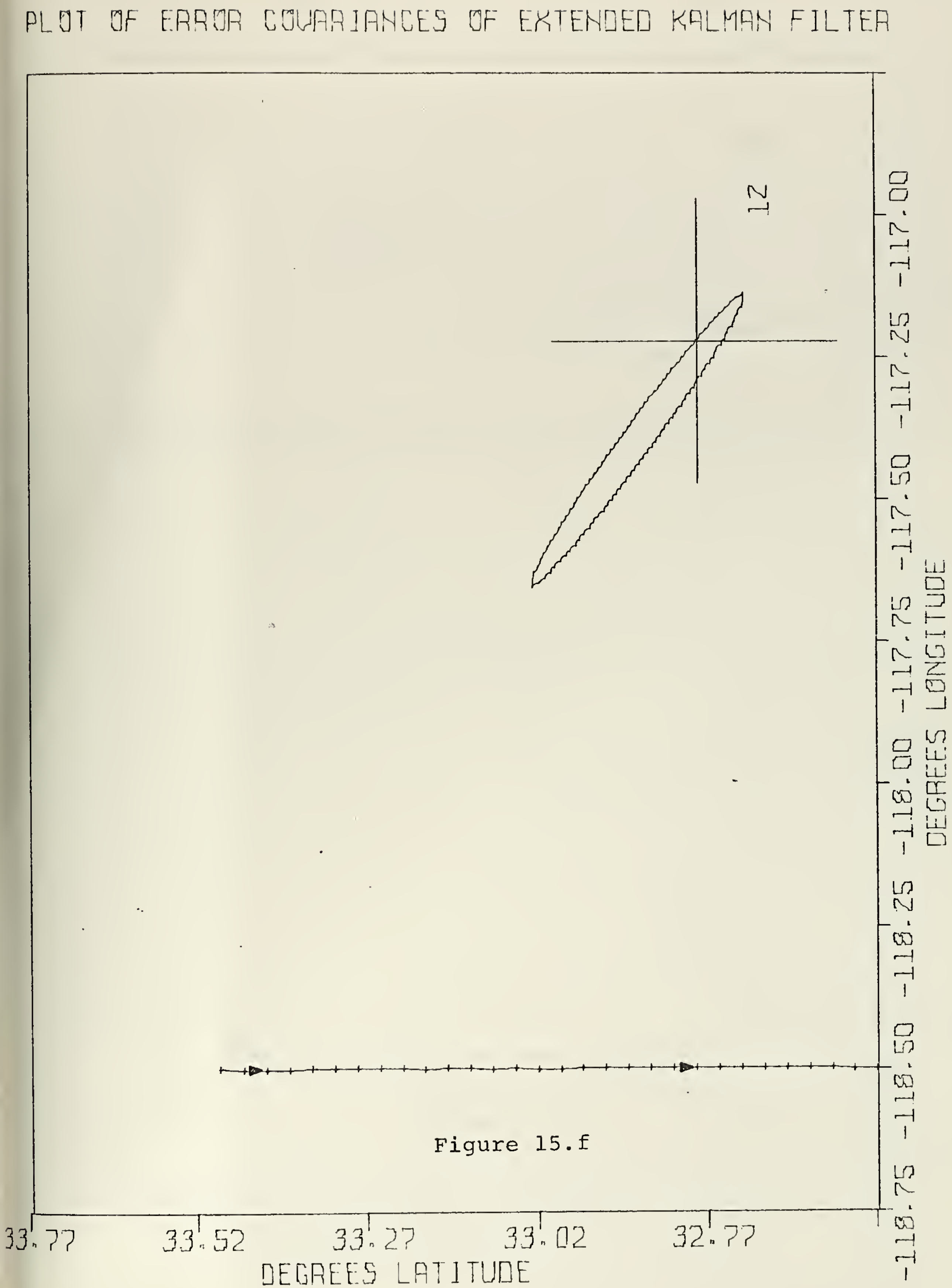
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
12
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE

Figure 15.f

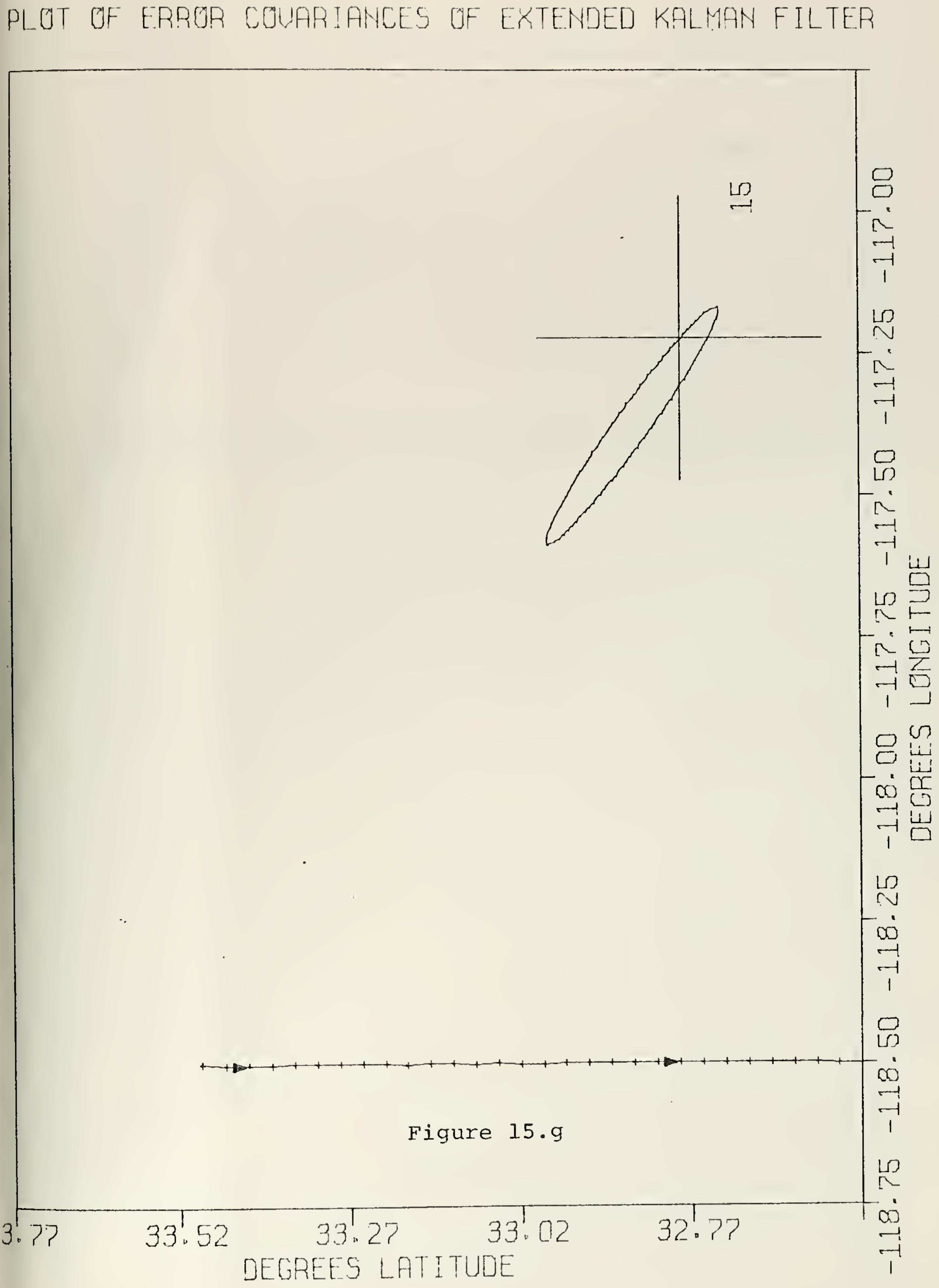
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
15
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE

Figure 15.g

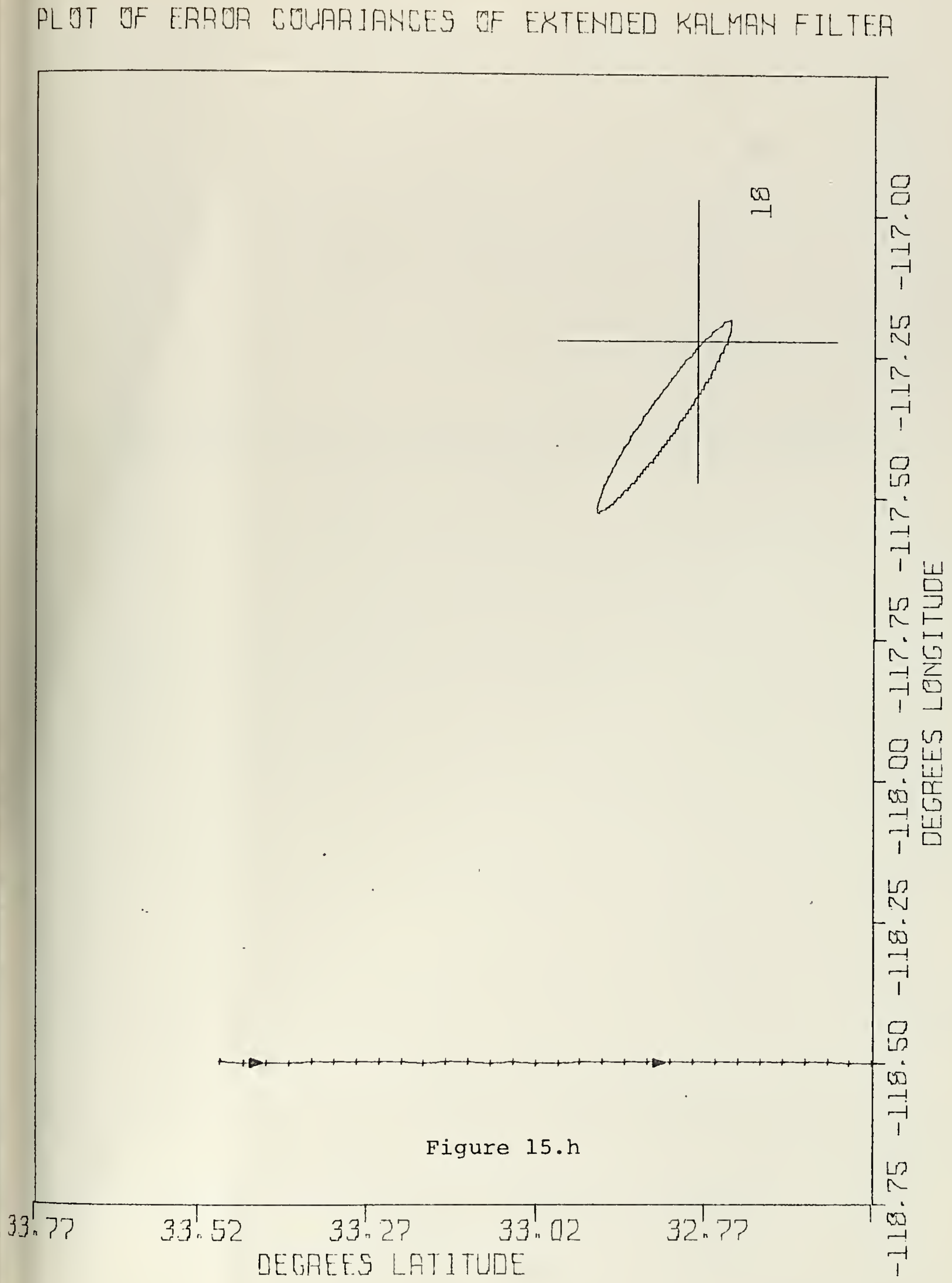
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
18
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE

Figure 15.h

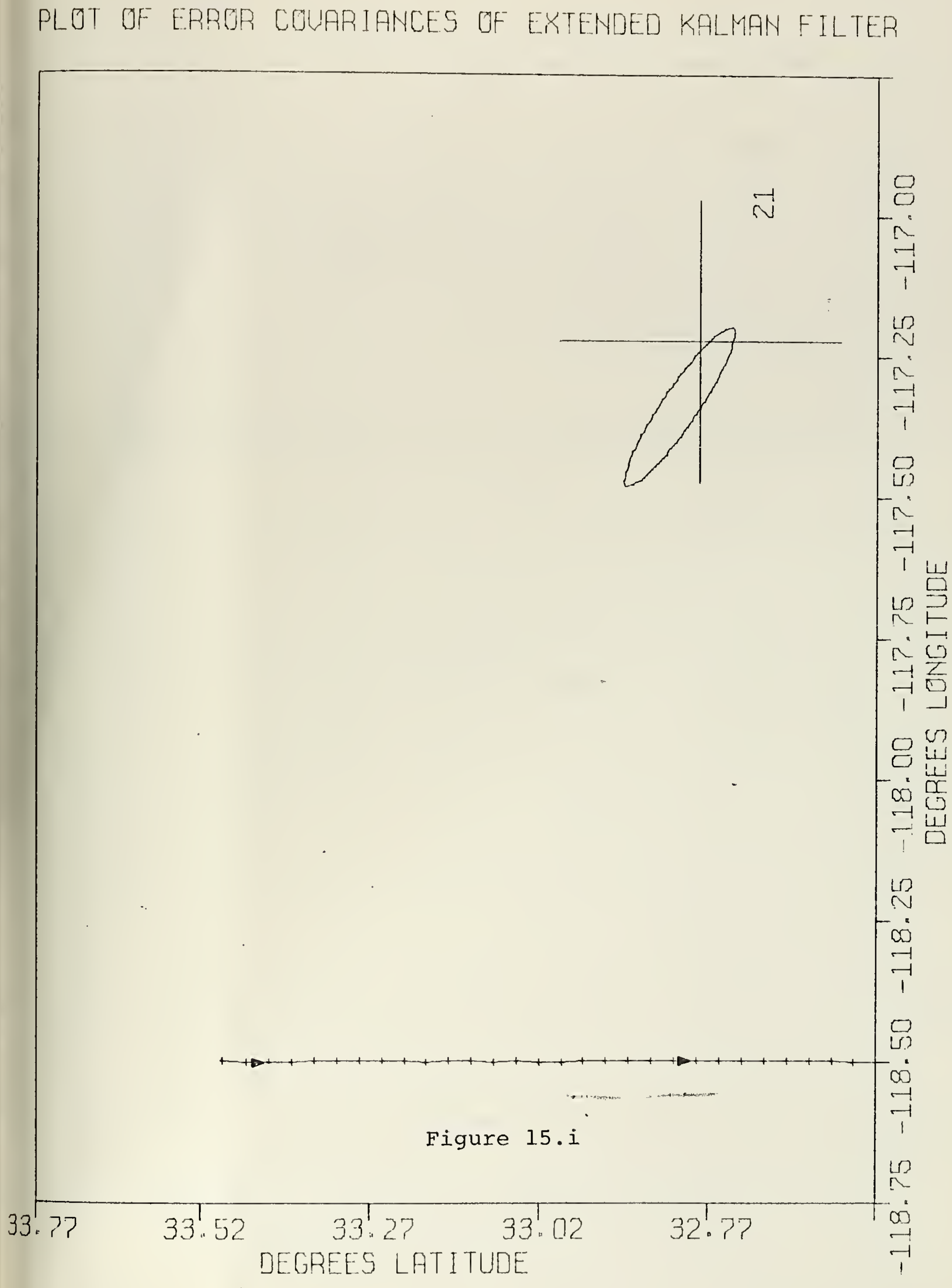
PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER
21
-117.00
-117.25
-117.50
-117.75
-118.00
-118.25
-118.50
-118.75
DEGREES LONGITUDE
33.77
33.52
33.27
33.02
32.77
DEGREES LATITUDE

Figure 15.i

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

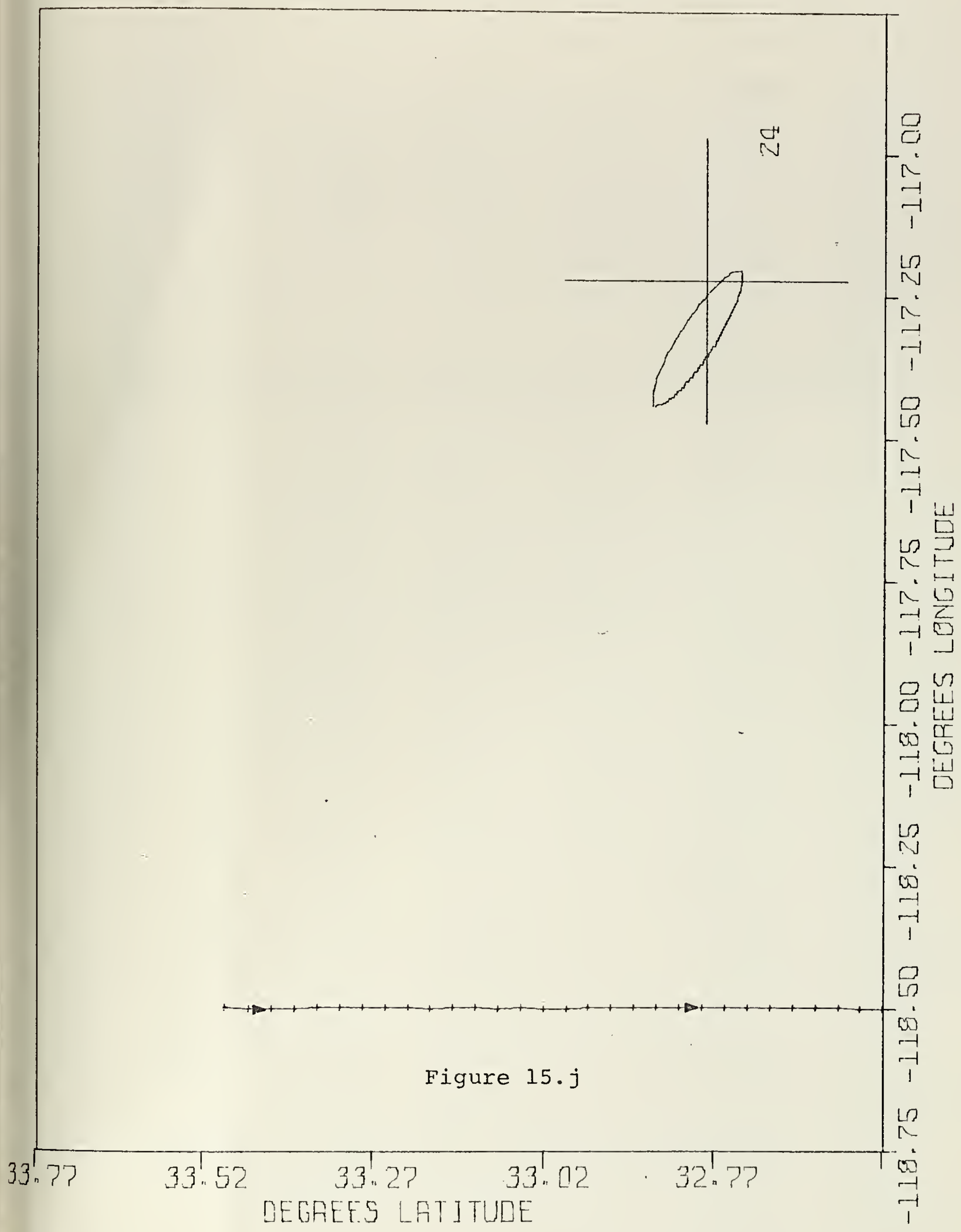

Figure 15.j

PLOT OF ERROR COVARIANCES OF EXTENDED KALMAN FILTER

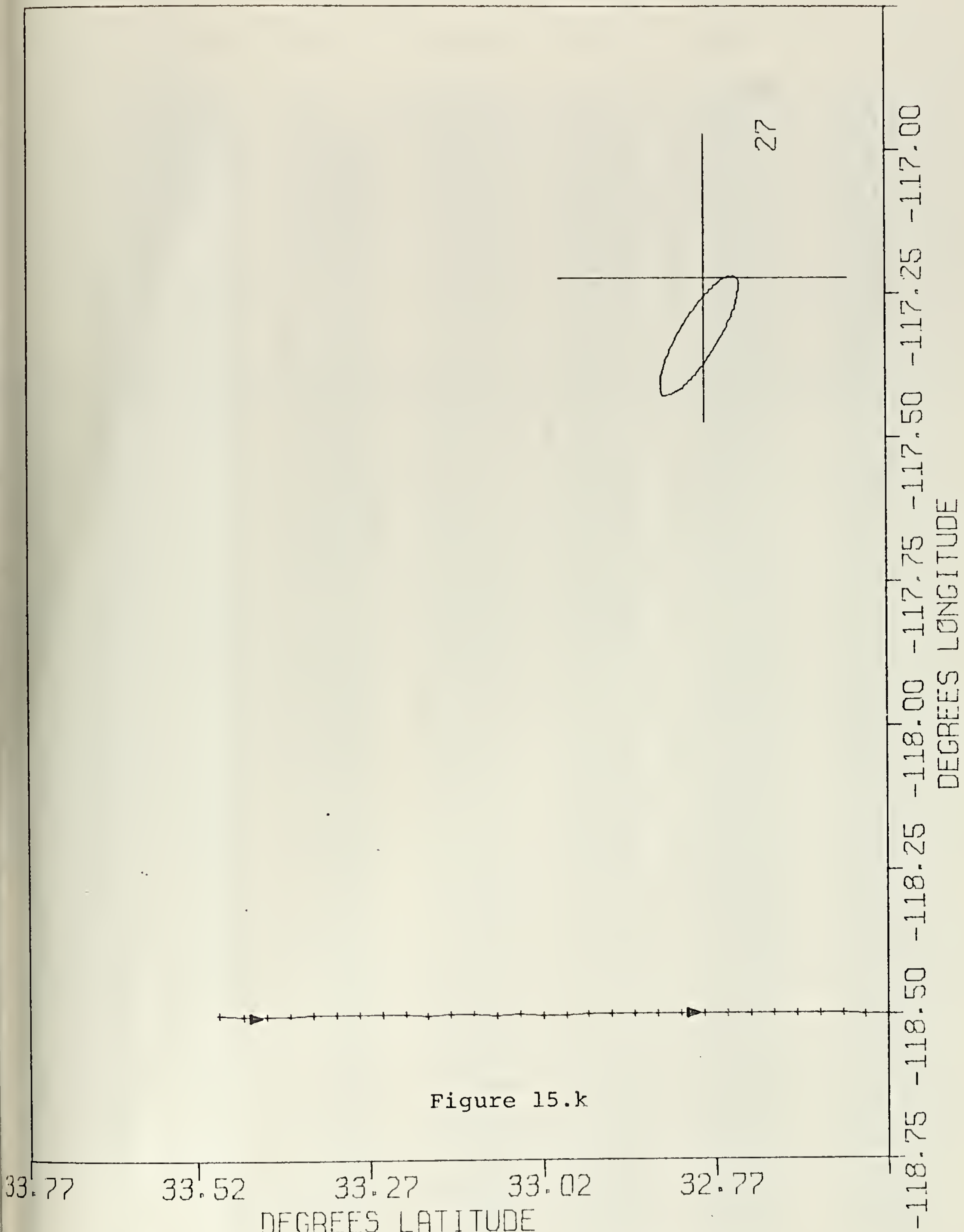

Figure 15.k

```
                NAVIGATION DATA FILTER PARAMETERS

 K      SG1         SG2          SP11         SP12         SP22          T


 1   0.0         0.0          1.00000     0.0          1.00000         0.0
 2   1.00000     0.05119380.66919 19.48511     1.00038        19.49
 3   0.99882     0.05108      1.14965     0.05879      0.00339        19.51
 4   0.98838     0.06558      0.08664     0.00575      0.00060        14.66
 5   0.98501     0.04940      0.08871     0.00445      0.00060        19.44
 6   0.99316     0.08664      0.00135     0.00012      0.00038         0.13
 7   0.98754     0.06699      0.08112     0.00550      0.00059        14.74
 8   0.98151     0.06026      0.05790     0.00355      0.00047        15.71
 9   0.97277     0.10268      0.02173     0.00229      0.00033         8.76
10   0.94145     0.08600      0.01088     0.00099      0.00019         9.74
11   0.94856     0.08194      0.01346     0.00116      0.00022        10.51
12   0.91888     0.15716      0.00328     0.00056      0.00014         4.17
13   0.85980     0.11550      0.00249     0.00034      0.00008         5.86
14   0.83806     0.13307      0.00140     0.00022      0.00006         3.91
15   0.85071     0.07386      0.00388     0.00034      0.00013         9.81
16   0.92033     0.12667      0.00475     0.00065      0.00014         5.93
17   0.86281     0.12924      0.00202     0.00030      0.00008         4.63
18   0.86374     0.08069      0.00394     0.00037      0.00012         8.95
19   0.90294     0.13523      0.00327     0.00049      0.00011         5.06
20   0.92028     0.05688      0.01188     0.00073      0.00027        14.82
21   0.95677     0.14607      0.00857     0.00131      0.00026         5.58
22   0.93741     0.06148      0.01462     0.00096      0.00026        14.05
23   0.94708     0.20048      0.00123     0.00026      0.00020         0.99
24   0.90285     0.21650      0.00257     0.00062      0.00017         3.98
25   0.83907     0.10200      0.00214     0.00026      0.00007         5.91
26   0.88344     0.07841      0.00506     0.00045      0.00013         9.61
27   0.95941     0.06027      0.02470     0.00155      0.00033        15.05
28   0.94919     0.18175      0.00512     0.00098      0.00025         3.95
29   0.92062     0.08575      0.00783     0.00073      0.00016         9.72
30   0.98201     0.11463      0.00064     0.00008      0.00010         0.17
31   0.96785     0.04331      0.04680     0.00209      0.00059        22.39
32   0.96556     0.26431      0.00448     0.00123      0.00051         2.30
33   0.96510     0.09523      0.01888     0.00186      0.00028         9.83
34   0.96078     0.06154      0.02486     0.00159      0.00032        14.62
35   0.97220     0.09061      0.02435     0.00227      0.00032        10.03
36   0.93132     0.17870      0.00090     0.00017      0.00012         0.96
37   0.91836     0.10144      0.00690     0.00076      0.00016         8.84
38   0.96472     0.04517      0.03873     0.00181      0.00050        20.40
39   0.95950     0.26424      0.00315     0.00087      0.00042         1.92
40   0.89174     0.32614      0.00132     0.00048      0.00020         2.30
41   0.88387     0.07968      0.00513     0.00046      0.00014         9.70
42   0.98371     0.10944      0.00061     0.00007      0.00010         0.15
43   0.97027     0.03956      0.05574     0.00227      0.00070        24.59
44   0.98900     0.09726      0.06107     0.00601      0.00070         9.78
45   0.92971     0.13186      0.00517     0.00073      0.00015         5.63
46   0.86633     0.12222      0.00233     0.00033      0.00008         5.17
47   0.82393     0.12997      0.00128     0.00020      0.00006         3.95
48   0.84651     0.07313      0.00376     0.00032      0.00013         9.82
49   0.92028     0.12684      0.00475     0.00065      0.00014         5.92
50   0.85657     0.13893      0.00165     0.00027      0.00007         3.97
51   0.81387     0.10611      0.00171     0.00022      0.00006         5.65
52   0.87628     0.08114      0.00449     0.00042      0.00012         9.13
53   0.95511     0.06082      0.02183     0.00139      0.00031        14.77
54   0.95369     0.15795      0.00706     0.00117      0.00025         4.94
55   0.88339     0.12346      0.00296     0.00041      0.00010         5.63
56   0.88633     0.08152      0.00496     0.00046      0.00013         9.15
57   0.88925     0.17660      0.00147     0.00029      0.00010         2.64
58   0.87054     0.09397      0.00385     0.00042      0.00011         8.23
59   0.94438     0.06346      0.01623     0.00109      0.00026        13.76
60   0.95553     0.17797      0.00110     0.00020      0.00020         0.74
61   0.95518     0.10369      0.01350     0.00147      0.00024         9.12
62   0.90990     0.13526      0.00345     0.00051      0.00012         4.92
63   0.85686     0.11034      0.00246     0.00032      0.00008         5.93
64   0.89314     0.07766      0.00575     0.00050      0.00014         9.91
65   0.90760     0.15759      0.00274     0.00048      0.00012         4.02
```

```
              NAVIGATION DATA FILTER PARAMETERS

 K   VELND      ELAT         SLATD     VELED     ELON      SLOND

 1 -0.00097  0.0          33.35472  0.00106   0.0      -120.90094
 2 -0.00097  0.0          33.33582  0.00103   0.00339  -120.88036
 3 -0.00097  0.00003      33.31688  0.00103   0.00391  -120.85689
 4 -0.00094  0.00047      33.30269  0.00104   0.00335  -120.83792
 5 -0.00097 -0.00066      33.28491  0.00105   0.00426  -120.81435
 6 -0.00096  0.00014      33.28412  0.00092   0.00063  -120.81000
 7 -0.00097 -0.00018      33.27011  0.00100   0.00411  -120.79581
 8 -0.00095  0.00037      33.25467  0.00103   0.00385  -120.77605
 9 -0.00092  0.00031      33.24670  0.00110   0.00274  -120.76324
10 -0.00098 -0.00078      33.23805  0.00103   0.00161  -120.74988
11 -0.00094  0.00055      33.22697  0.00099   0.00181  -120.73749
12 -0.00095 -0.00005      33.22357  0.00099   0.00121  -120.73164
13 -0.00097 -0.00018      33.21797  0.00099   0.00166  -120.72475
14 -0.00100 -0.00024      33.21402  0.00100   0.00157  -120.71945
15 -0.00095  0.00061      33.20399  0.00098   0.00231  -120.70831
16 -0.00095  0.00003      33.19885  0.00103   0.00202  -120.70053
17 -0.00097 -0.00015      33.19446  0.00100   0.00125  -120.69388
18 -0.00096  0.00008      33.18562  0.00100   0.00245  -120.68384
19 -0.00092  0.00032      33.18080  0.00103   0.00169  -120.67664
20 -0.00083  0.00166      33.16742  0.00112   0.00536  -120.65984
21 -0.00072  0.00075      33.16432  0.00127   0.00273  -120.64865
22 -0.00066  0.00098      33.15494  0.00123   0.00333  -120.62817
23 -0.00074 -0.00041      33.15518  0.00122   0.00110  -120.62381
24 -0.00060  0.00063      33.15184  0.00119   0.00096  -120.61790
25 -0.00064 -0.00035      33.14882  0.00113   0.00155  -120.60997
26 -0.00070 -0.00076      33.14235  0.00120   0.00379  -120.59779
27 -0.00069  0.00015      33.13112  0.00124   0.00463  -120.57643
28 -0.00071 -0.00012      33.12852  0.00128   0.00162  -120.56711
29 -0.00071  0.00008      33.12146  0.00121   0.00188  -120.55310
30 -0.00069  0.00014      33.12140  0.00108   0.00074  -120.55115
31 -0.00069  0.00002      33.10605  0.00120   0.00810  -120.52617
32 -0.00072 -0.00012      33.10446  0.00147   0.00211  -120.51556
33 -0.00070  0.00024      33.09723  0.00125   0.00024  -120.49902
34 -0.00070 -0.00008      33.08723  0.00123   0.00341  -120.48045
35 -0.00069  0.00018      33.08009  0.00124   0.00285  -120.46487
36 -0.00067  0.00012      33.07959  0.00118   0.00095  -120.46089
37 -0.00065  0.00017      33.07381  0.00121   0.00251  -120.44954
38 -0.00070 -0.00108      33.06073  0.00123   0.00590  -120.42265
39 -0.00080 -0.00040      33.05833  0.00137   0.00152  -120.41460
40 -0.00058  0.00069      33.05611  0.00117   0.00008  -120.40997
41 -0.00067 -0.00119      33.05110  0.00118   0.00295  -120.39854
42 -0.00074 -0.00060      33.04994  0.00109   0.00110  -120.39574
43 -0.00070  0.00096      33.03119  0.00121   0.00895  -120.36789
44 -0.00064  0.00058      33.02527  0.00136   0.00425  -120.34735
45 -0.00069 -0.00037      33.02220  0.00125   0.00102  -120.33548
46 -0.00068  0.00014      33.01826  0.00121   0.00151  -120.32803
47 -0.00070 -0.00017      33.01570  0.00120   0.00169  -120.32196
48 -0.00066  0.00053      33.00870  0.00120   0.00319  -120.30882
49 -0.00066 -0.00002      33.00523  0.00128   0.00262  -120.29903
50 -0.00061  0.00034      33.00259  0.00126   0.00161  -120.29149
51 -0.00067 -0.00049      32.99940  0.00121   0.00165  -120.28296
52 -0.00069 -0.00032      32.99294  0.00121   0.00284  -120.27060
53 -0.00070 -0.00012      32.98242  0.00124   0.00454  -120.25027
54 -0.00070  0.00002      32.97885  0.00124   0.00146  -120.23978
55 -0.00071 -0.00008      32.97493  0.00121   0.00168  -120.23140
56 -0.00069  0.00017      32.96838  0.00120   0.00262  -120.21881
57 -0.00067  0.00014      32.96669  0.00121   0.00141  -120.21332
58 -0.00069 -0.00020      32.96130  0.00121   0.00251  -120.20207
59 -0.00071 -0.00031      32.95168  0.00123   0.00397  -120.18315
60 -0.00072 -0.00008      32.95087  0.00118   0.00101  -120.17848
61 -0.00075 -0.00032      32.94423  0.00122   0.00264  -120.16670
62 -0.00072  0.00026      32.94022  0.00123   0.00175  -120.15816
63 -0.00069  0.00027      32.93619  0.00117   0.00151  -120.14929
64 -0.00073 -0.00060      32.92961  0.00119   0.00321  -120.13641
65 -0.00073  0.00002      32.92613  0.00127   0.00205  -120.12874
```

```
                     LOB NUMBER ASSIGNED TO TARGET I

          1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18

   1      1   2   4   6   7   9  10  14  15  19  28  32  33  37  40  42  48  53  54  59
   2      3  20  24  30  35  43  44  50  61  65
   3      5  18  29  34  41
   4      8  13  16  23  25  27  36  46  49  58  63  64
   5     11  17  21  26  38  45  51  55  60
   6     12  22  47  52  56  62
   7     31  39  57
```

```
NAL JSET DATA



             LOB NUMBER ASSIGNED TO TARGET I

      1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18

1     1  2  4  6  7  9 10 14 15 19 28 32 33 37 40 42 48 53 54 59
2     3 20 30 35 43 44 50 61 65
3     5 18 29 34 41
4     8 13 16 46 49
5    11 17 38 45 51 55 60
6    12 22 47 52 56
7    31 39 57
8    24
9    23 25 27 36 58 63 64
0    21 26
1    62
```

```
        KALMAN FILTER PARAMETERS FOR ANGLE FILTER

  I    J    K         P11(K)           P12(K)        G1(K)       G2(K)

  1    0    1       10000.0000          0.0          0.9858      0.0
  1    2    2     3796832.0000     194851.0625       1.0000      0.0513
  1    3    4        1524.5747         32.8987       0.9137      0.0197
  1    4    6         280.4939          4.7693       0.6608      0.0112
  1    5    7         152.7203          2.2873       0.5147      0.0077
  1    6    9         145.1893          1.7950       0.5021      0.0062
  1    7   10          91.3717          1.0639       0.3882      0.0045
  1    8   14          95.3233          0.9622       0.3983      0.0040
  1    9   15          69.6211          0.6718       0.3259      0.0031
  1   10   19          73.6805          0.6359       0.3385      0.0029
  1   11   28         144.8281          0.8791       0.5014      0.0030
  1   12   32         113.2626          0.7491       0.4403      0.0029
  1   13   33          72.4155          0.4980       0.3346      0.0023
  1   14   37          79.2565          0.5709       0.3550      0.0026
  1   15   40          73.2924          0.5326       0.3373      0.0025
  1   16   42          56.1020          0.4119       0.2804      0.0021
  1   17   48          93.4777          0.6047       0.3936      0.0025
  1   18   53          96.7548          0.6493       0.4019      0.0027
  1   19   54          61.8750          0.4227       0.3005      0.0021
  1   20   59          76.1122          0.5372       0.3458      0.0024
  2    0    3       10000.0000          0.0          0.9858      0.0
  2    2   20   245938448.0000    1568242.0000       1.0000      0.0064
  2    3   30         538.0237          3.6306       0.7889      0.0053
  2    4   35         290.0398          2.2160       0.6682      0.0051
  2    5   43         276.5554          1.8841       0.6576      0.0045
  2    6   44         108.5593          0.7722       0.4298      0.0031
  2    7   50         104.9692          0.8097       0.4216      0.0033
  2    8   61         204.2398          1.2454       0.5865      0.0036
  2    9   65         117.2222          0.8081       0.4487      0.0031
  3    0    5       10000.0000          0.0          0.9858      0.0
  3    2   18   105753904.0000    1028366.6875       1.0000      0.0097
  3    3   29         676.7473          4.5293       0.8246      0.0055
  3    4   34         240.9335          1.6838       0.6259      0.0044
  3    5   41         196.7235          1.3391       0.5774      0.0039
  4    0    8       10000.0000          0.0          0.9858      0.0
  4    2   13    15236810.0000     390341.7500       1.0000      0.0256
  4    3   16         364.8191          7.4582       0.7170      0.0147
  4    4   46        6361.5547         22.8240       0.9779      0.0035
  4    5   49         186.0658          1.7933       0.5637      0.0054
  5    0   11       10000.0000          0.0          0.9858      0.0
  5    2   17    11760551.0000     342934.5625       1.0000      0.0292
  5    3   38       10214.9727         49.5509       0.9861      0.0048
  5    4   45         334.0320          2.8629       0.6988      0.0060
  5    5   51         190.9865          1.7584       0.5701      0.0052
  5    6   55         155.5254          1.3744       0.5192      0.0046
  5    7   60         135.6935          1.1037       0.4852      0.0039
  6    0   12       10000.0000          0.0          0.9858      0.0
  6    2   22    61762576.0000     785891.0625       1.0000      0.0127
  6    3   47        2935.1575         11.3428       0.9532      0.0037
  6    4   52         228.4055          2.1122       0.6133      0.0057
  6    5   56         186.3982          2.0266       0.5642      0.0061
  7    0   31       10000.0000          0.0          0.9858      0.0
  7    2   39    47449840.0000     688837.8750       1.0000      0.0145
  7    3   57        1653.8228          9.3628       0.9199      0.0052
  9    0   23       10000.0000          0.0          0.9858      0.0
  9    2   25      977951.8125      98884.2500       0.9999      0.1011
  9    3   27        2646.6462         86.8112       0.9484      0.0311
  9    4   36        2056.0347         21.4738       0.9345      0.0098
  9    5   58        1380.1123          5.8268       0.9055      0.0038
  9    6   63         207.6056          1.6897       0.5905      0.0048
  9    7   64         101.2973          0.9508       0.4130      0.0039
 10    0   21       10000.0000          0.0          0.9858      0.0
 10    2   26    11934835.0000     345466.2500       1.0000      0.0289
```

```
          KALMAN FILTER PARAMETERS FOR ANGLE FILTER


  I    J    K     T(K)      THTD(K)    TDTD(K)     E(K)        GATE(K)

  1    0    1     0.0       59.2273    -0.0479
  1    2    2    19.485     57.7483    -0.0759   -0.5454      974.2915
  1    3    4    34.179     56.1255    -0.0549    1.0632       20.4241
  1    4    6    19.573     55.1541    -0.0532    0.1573       10.3016
  1    5    7    14.742     53.9223    -0.0599   -0.8703        8.6128
  1    6    9    24.466     52.5216    -0.0591    0.1281        8.5028
  1    7   10     9.744     51.7402    -0.0615   -0.5299        7.6709
  1    8   14    24.439     50.4772    -0.0591    0.6015        7.7350
  1    9   15     9.806     49.6654    -0.0613   -0.7137        7.3079
  1   10   19    24.569     47.8786    -0.0637   -0.8289        7.3770
  1   11   28    73.938     42.7536    -0.0662   -0.8239        8.4975
  1   12   32    34.578     40.5205    -0.0659    0.1300        8.0197
  1   13   33     9.831     39.7742    -0.0665   -0.2954        7.3555
  1   14   37    34.441     37.5330    -0.0662    0.1419        7.4709
  1   15   40    24.613     35.8449    -0.0666   -0.1759        7.3704
  1   16   42     9.847     35.1225    -0.0671   -0.2374        7.0729
  1   17   48    58.940     31.0783    -0.0677   -0.2278        7.7052
  1   18   53    39.444     28.1404    -0.0695   -0.6683        7.7581
  1   19   54     4.937     27.7536    -0.0698   -0.1458        7.1742
  1   20   59    39.424     24.7081    -0.0719   -0.8522        7.4181
  2    0    3     0.0       62.3831    -0.0473
  2    2   20   156.824     54.0991    -0.0528   -0.8639     7841.2148
  2    3   30    69.009     51.0311    -0.0489    0.7317       13.0578
  2    4   35    59.161     48.0350    -0.0497   -0.1518       10.4168
  2    5   43    68.851     46.0922    -0.0396    2.2497       10.2537
  2    6   44     9.783     45.3923    -0.0418   -0.7265        7.9461
  2    7   50    34.461     43.0553    -0.0487   -2.1226        7.8894
  2    8   61    83.767     38.9379    -0.0490   -0.0577        9.3306
  2    9   65    24.765     37.8015    -0.0484    0.1693        8.0812
  3    0    5     0.0       76.3184    -0.0423
  3    2   18   102.837     73.9504    -0.0230    1.9865     5141.8398
  3    3   29    88.724     70.5609    -0.0320   -1.6330       14.3243
  3    4   34    49.304     69.2111    -0.0304    0.3671        9.8099
  3    5   41    54.138     67.6206    -0.0300    0.0988        9.2293
  4    0    8     0.0       89.8662    -0.0351
  4    2   13    39.034     87.7937    -0.0531   -0.7037     1951.7271
  4    3   16    19.638     86.8632    -0.0508    0.1565       11.2785
  4    4   46   251.067     70.9110    -0.0623   -3.2701       40.3285
  4    5   49    19.688     69.7662    -0.0615    0.1441        9.0839
  5    0   11     0.0       88.4148    -0.0363
  5    2   17    34.293     86.4644    -0.0569   -0.7063     1714.6934
  5    3   38   187.198     76.1742    -0.0551    0.3616       50.8895
  5    4   45    54.068     72.2144    -0.0635   -1.3999       10.9320
  5    5   51    34.479     69.2354    -0.0708   -1.3831        9.1513
  5    6   55    34.468     66.8928    -0.0699    0.1874        8.6534
  5    7   60    34.529     63.3594    -0.0790   -2.3061        8.3620
  6    0   12     0.0       52.8601    -0.0490
  6    2   22    78.589     44.0398    -0.1122   -4.9659     3929.4629
  6    3   47   201.919     34.5715    -0.0612   13.8409       27.7451
  6    4   52    34.488     32.3674    -0.0621   -0.1496        9.6489
  6    5   56    34.495     28.9272    -0.0762   -2.3011        9.0884
  7    0   31     0.0       48.3618    -0.0478
  7    2   39    68.884     44.3147    -0.0588   -0.7557     3444.1973
  7    3   57   132.894     37.7173    -0.0519    1.3159       21.2004
  9    0   23     0.0       37.0618    -0.0497
  9    2   25     9.888     36.0716    -0.1001   -0.4992      494.4937
  9    3   27    24.660     36.3181    -0.0111    2.8634       26.4133
  9    4   36    73.959     33.0763    -0.0364   -2.5942       23.4523
  9    5   58   172.278     24.4576    -0.0463   -2.5979       19.5199
  9    6   63    34.466     20.1427    -0.0684   -4.6048        9.3756
  9    7   64     9.906     18.3441    -0.0790   -2.7139        7.8310
 10    0   21     0.0       36.2854    -0.0497
 10    2   26    34.547     35.1806    -0.0320    0.6114     1727.3518
```

```
                        TARGET NUMBER   1

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER   1

  K   FREQ    PRF    PW      THETAD      THTD       SLAD       SLOD

  1 2872.0 320.0 2.40    59.2273    59.2273    33.3547 -120.8981
  2 2872.0 322.0 2.50    57.7483    57.7483    33.3358 -120.8769
  4 2872.0 320.0 2.50    56.2173    56.1255    33.3031 -120.8344
  6 2872.0 318.0 2.40    55.2075    55.1541    33.2842 -120.8093
  7 2872.0 320.0 2.60    53.5000    53.9223    33.2699 -120.7916
  9 2872.0 319.0 2.20    52.5854    52.5216    33.2468 -120.7605
 10 2872.0 321.0 2.50    51.4160    51.7402    33.2374 -120.7481
 14 2872.0 320.0 2.60    50.8391    50.4772    33.2140 -120.7176
 15 2872.0 320.0 2.20    49.1843    49.6654    33.2045 -120.7058
 19 2872.0 320.0 2.40    47.3303    47.8786    33.1813 -120.6743
 28 2872.0 319.0 2.60    42.3428    42.7536    33.1284 -120.5652
 32 2872.0 319.0 2.50    40.5933    40.5205    33.1044 -120.5135
 33 2872.0 320.0 2.50    39.5776    39.7742    33.0974 -120.4985
 37 2872.0 320.0 2.40    37.6245    37.5330    33.0738 -120.4462
 40 2872.0 320.0 2.50    35.7283    35.8449    33.0555 -120.4081
 42 2872.0 320.0 2.50    34.9517    35.1225    33.0494 -120.3945
 48 2872.0 319.0 2.30    30.9402    31.0783    33.0092 -120.3054
 53 2872.0 323.0 2.80    27.7407    28.1404    32.9823 -120.2458
 54 2872.0 320.0 2.50    27.6516    27.7536    32.9788 -120.2381
 59 2872.0 322.0 2.50    24.1506    24.7081    32.9514 -120.1793

  SMOOTHED INITIAL BEARING ANGLE =  59.22725 N

     FILTERED FINAL BEARING ANGLE =  24.70815 W


           VECTOR METHOD SOLUTION OF EMITTER LOCATION

                  EMITTER LATITUDE =  33.98700 N

                EMITTER LONGITUDE =-119.60393 W
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                        TARGET NUMBER   2

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER   2

  K   FREQ    PRF    PW      THETAD      THTD       SLAD      SLOD

  3 2876.0 306.0 2.40     62.3831     62.3831     33.3169 -120.8529
 20 2878.0 304.0 2.40     54.0991     54.0991     33.1691 -120.6545
 30 2878.0 306.0 2.30     51.1855     51.0311     33.1215 -120.5503
 35 2876.0 306.0 2.30     47.9846     48.0350     33.0803 -120.4621
 43 2876.0 306.0 2.40     46.8625     46.0922     33.0322 -120.3590
 44 2876.0 306.0 2.30     44.9780     45.3923     33.0258 -120.3431
 50 2876.0 306.0 2.50     41.8276     43.0553     33.0027 -120.2898
 61 2876.0 306.0 2.30     38.9141     38.9379     32.9440 -120.1640
 65 2876.0 306.0 2.40     37.8948     37.8015     32.9261 -120.1269

  SMOOTHED INITIAL BEARING ANGLE =  62.38292 N

    FILTERED FINAL BEARING ANGLE =  37.80147 W


            VECTOR METHOD SOLUTION OF EMITTER LOCATION

                  EMITTER LATITUDE =  34.09401 N

                 EMITTER LONGITUDE =-119.02849 W
```

```
                    TARGET NUMBER  3

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER  3

  K  FREQ    PRF   PW     THETAD      THTD       SLAD       SLOD

  5 2846.0 370.0 2.30    76.3184    76.3184    33.2843 -120.8101
 18 2846.0 370.0 2.30    73.9504    73.9504    33.1857 -120.6813
 29 2846.0 370.0 2.40    70.2744    70.5609    33.1215 -120.5511
 34 2846.0 370.0 2.40    69.3484    69.2111    33.0872 -120.4769
 41 2846.0 370.0 2.40    67.6624    67.6206    33.0495 -120.3957

  SMOOTHED INITIAL BEARING ANGLE =  76.31851 N

    FILTERED FINAL BEARING ANGLE =  67.62057 W


          VECTOR METHOD SOLUTION OF EMITTER LOCATION

               EMITTER LATITUDE =  33.78937 N

              EMITTER LONGITUDE =-118.17609 W
```

```
                        TARGET NUMBER   4

 FILTERED AND  SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER   4

   K   FREQ     PRF    PW      THETAD       THTD        SLAD        SLOD

   8 5556.0 320.0 1.00      89.8662     89.8662     33.2550 -120.7721
  13 5554.0 640.0 1.10      87.7937     87.7937     33.2177 -120.7229
  16 5556.0 320.0 1.00      86.9075     86.8632     33.1988 -120.6985
  46 5554.0 640.0 0.90      70.8386     70.9110     33.0182 -120.3263
  49 5554.0 320.0 1.00      69.8291     69.7662     33.0054 -120.2964

   SMOOTHED INITIAL BEARING ANGLE =   89.86671 N

     FILTERED FINAL BEARING ANGLE =   69.76620 W


           VECTOR METHOD SOLUTION OF EMITTER LOCATION

                  EMITTER LATITUDE =   33.25092 N

                 EMITTER LONGITUDE =-119.49136 W
```

```
                    TARGET NUMBER   5

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER  5

  K  FREQ    PRF    PW     THETAD      THTD       SLAD       SLOD

 11 5506.0 640.0 0.60     88.4148     88.4148    33.2275 -120.7356
 17 5504.0 640.0 0.60     86.4644     86.4644    33.1942 -120.6923
 38 5504.0 640.0 0.60     76.1792     76.1742    33.0597 -120.4169
 45 5506.0 640.0 0.70     71.7927     72.2144    33.0218 -120.3343
 51 5504.0 642.0 0.60     68.6409     69.2354    32.9989 -120.2809
 55 5504.0 640.0 0.60     66.9829     66.8928    32.9749 -120.2294
 60 5504.0 642.0 0.60     62.1721     63.3594    32.9508 -120.1774

  SMOOTHED INITIAL BEARING ANGLE =  88.41481 N

    FILTFRED FINAL BEARING ANGLE =  63.35942 W


          VECTOR METHOD SOLUTION OF EMITTER LOCATION

                EMITTER LATITUDE =  33.25052 N

               EMITTER LONGITUDE =-119.45798 W
```

```
                         TARGET NUMBER  6

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER  6

  K  FREQ    PRF   PW     THETAD      THTD       SLAD       SLOD

 12 2876.0 359.0 2.20    52.8601    52.8601    33.2234 -120.7302
 22 2876.0 359.0 2.20    44.0398    44.0398    33.1556 -120.6249
 47 2876.0 359.0 2.40    35.2188    34.5715    33.0157 -120.3198
 52 2874.0 359.0 2.40    32.3096    32.3674    32.9926 -120.2671
 56 2876.0 359.0 2.20    27.9243    28.9272    32.9686 -120.2162

  SMOOTHED INITIAL BEARING ANGLE =   52.85960 N

    FILTERED FINAL BEARING ANGLE =   28.92722 W


           VECTOR METHOD SOLUTION OF EMITTER LOCATION

                 EMITTER LATITUDE =   33.95410 N

                EMITTER LONGITUDE =-119.55852 W
```

```
                    TARGET NUMBER  7

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER  7

 K  FREQ    PRF    PW     THETAD      THTD       SLAD       SLOD

31 9268.0 500.0 0.20    48.3618    48.3618    33.1060 -120.5182
39 9268.0 499.0 0.20    44.3147    44.3147    33.0578 -120.4130
57 9270.0 500.0 0.30    37.8228    37.7173    32.9668 -120.2116

 SMOOTHED INITIAL BEARING ANGLE =  48.36174 N
   FILTERED FINAL BEARING ANGLE =  37.71735 W


          VECTOR METHOD SOLUTION OF EMITTER LOCATION
                EMITTER LATITUDE =  34.12042 N
               EMITTER LONGITUDE =-119.12958 W
```

```
                       TARGET NUMBER   8

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER  8

  K   FREQ    PRF    PW     THETAD      THTD       SLAD       SLOD
 24 2876.0 305.0 2.40    19.1616                 33.1525 -120.6167

                       SINGLE LINE BEARING
```

```
                    TARGET NUMBER   9

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER   9

  K   FREQ    PRF    PW      THETAD      THTD       SLAD       SLOD

 23 5556.0 640.0 1.00    37.0618    37.0618    33.1548 -120.6227
 25 5556.0 320.0 1.10    36.0715    36.0716    33.1482 -120.6078
 27 5554.0 640.0 1.10    36.4658    36.3181    33.1312 -120.5719
 36 5554.0 640.0 1.10    32.9065    33.0763    33.0797 -120.4598
 58 5556.0 640.0 1.00    24.2122    24.4576    32.9610 -120.1989
 63 5556.0 640.0 1.00    18.2568    20.1427    32.9362 -120.1472
 64 5556.0 320.0 1.10    16.7510    18.3441    32.9291 -120.1331

  SMOOTHED INITIAL BEARING ANGLE =   37.06157 N

    FILTERED FINAL BEARING ANGLE =   18.34413 W


          VECTOR METHOD SOLUTION OF EMITTER LOCATION

                EMITTER LATITUDE =   34.27957 N

               EMITTER LONGITUDE =-119.59087 W
```

```
                    TARGET NUMBER 10

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER 10

  K  FREQ    PRF    PW     THETAD      THTD       SLAD       SLOD

 21 5504.0 640.0 0.60    36.2854    36.2854    33.1652 -120.6456
 26 5504.0 640.0 0.60    35.1807    35.1806    33.1417 -120.5935

  SMOOTHED INITIAL BEARING ANGLE =  36.28545 N

    FILTERED FINAL BEARING ANGLE =  35.18065 W


          VECTOR METHOD SOLUTION OF EMITTER LOCATION

                EMITTER LATITUDE =  35.15515 N

               EMITTER LONGITUDE =-118.84724 W
```

```
                   TARGET NUMBER 11

FILTERED AND SMOOTHED EMITTER DATA CORRELATED TO TARGET NUMBER 11

  K  FREQ    PRF   PW     THETAD      THTD       SLAD       SLOD
 62 2874.0 359.0 2.40    59.5566               32.9406 -120.1563

                   SINGLE LINE BEARING
```

```
C     .....................................................
C
C     MASTER CONTROL PROGRAM
C
C     DESCRIPTION OF VARIABLES IN THE COMMON BLOCK
C
C     ACLAD
C     ACLAMD
C     ACLAR  - AIRCRAFT LATITUDE READ FORM DATA
C     ACLOD
C     ACLOMD
C     ACLOR  - AIRCRAFT LONGITUDE READ FROM DATA
C     ALT    - AIRCRAFT ALTITUDE
C     BRNG
C     BRNGD  - DF BEARING ANGLE (TRUE OR RELATIVE, DEPENDING
C              ON DATA SOURCE)
C     E      - KALMAN FILTER ERROR TERM IN ANGLE FILTER
C     FREQ   - SIGNAL FREQUENCY IN MEGACYCLES
C     G1
C     G2     - KALMAN FILTER GAINS
C     GATE   - TEST FOR DF BEARING CORRELATION
C     HDG
C     HDGD   - AIRCRAFT HEADING (TRUE)
C     MODEN
C     MODET  - MODE OF DATA COLLECTOR OPERATION
C     NST    - NUMBER OF DF BEARINGS CORRELATED TO A TARGET
C     P11
C     P12
C     P22    - ERROR COVARIANCE TERMS
C     PITCH  - LONGITUDINAL ATTITUDE OF AIRCRAFT
C     PRF    - SIGNAL PULEE REPITION FREQUENCY
C     PRF    - SIGNAL PULSE REPITION FREQUENCY
C     PW     - SIGNAL PULSE WIDTH
C     ROLL   - TRANSVERSE ATTITUDE OF AIRCRAFT
C     SLA
C     SLAD   - FILTERED AND SMOOTHED AIRCRAFT LATITUDE
C     SLO
C     SLOD   - FILTERED AND SMOOTHED LONGITUDE OF AIRCRAFT
C     T      - TIME BETWEEN DATA SETS (SECONDS)
C     TIMEN  - TIME OF NAVIGATIONAL FIXES
C     TIMET  - TIME OF TAKING DF BEARING
C     TDTD   - DF BEARING ANGLE RATE
C     THTD   - FILTERED DF BEARING ANGLE
C     THTD1  - SMOOTHED FIRST OF BEARING ANGLE
C     THETA
C     THETAD- DF BEARING ANGLE FROM DATA (TRUE)
C     TLAD   - TARGET LATITUDE FROM ANGLE FILTERING
C     TLOD   - TARGET LONGITUDE FROM ANGLE FILTERING
C     VEL    - AIRCRAFT SPEED OVER THE GROUND
C     VELE   - AIRCRAFT VELOCITY IN EAST DIRECTION (NEGATIVE
C              DENOTES AIRCRAFT HEADING WEST)
C     VELN   - AIRCRAFT VELOCITY IN NORTH DIRECTION (NEGATIVE
C              NUMBER INDICATES THAT THE AIRCRAFT IS HEADING
C     XTD1   - TARGET LONGITUDE FROM EXTENDED KALMAN FILTER
C     YTD1   - TARGET LATITUDE FROM EXTENDED KALMAN FILTER
C     D11    - COVARIANCE OF ERROR OF SMOOTHED FIRST DF
C              BEARING
C     JST    - NUMBER OF DF BEARINGS FILTERED IN ANGLE FILTER
C              BEFORE PROCESSING SWITCHED TO EXTENDED KALMAN
C
C     VARIABLES COMMON THROUGHOUT PROGRAM
C
C     JSET   - MATRIX RELATING DATA SETS TO TARGETS
C     PTLAT  - MATRIX OF LATITUDE OF INTERSECTION OF ERROR
C              CONES ASSOCIATED WITH EACH BEARING
C     PTLON  - MATRIX OFLCNGITUDE OF INTERSECTION OF ERROR
C              CONES ASSOCIATED WITH EACH DF BEARING
C     NSTA   - NUMBER OF DF BEARINGS CORRELATED TO A TARGET
C     JSTA   - NUMBER OF DF BEARINGS FILTERED BEFORE
C              PROCESSING SWITCHED TO EXTENDED KALMAN FILTER
C
C     .....................................................
```

```
C
      COMMON ACLAD(100),ACLAMD(100),ACLAR(100),ACLOD(100),
     1ACLOMD(100),ACLOR(100),ALT(100),BRNG(100),BRNGD(100),
     2E(100),FREQ(100),G1(100),G2(100),GATE(100),HDG(100),
     3HDGD(100),MODEN(100),MODET(100),NST(100),P11(100),
     4P12(100),P22(100),PITCH(100),PRF(100),PW(100),
     5ROLL(100),SLA(100),SLAD(100),SLO(100),SLOD(100),
     5T(100),TIMEN(100),TIMET(100),TDTD(100),THTD(100),
     6THTD1(100),THETA(100),THETAD(100),TLAD(100),TLOD(100),
     7VEL(100),VELE(100),VELN(100),XTD(100),YTD(100),
     8D11(100),JST(100)
      DIMENSION JSET(15,50),PTLAT(4,15,50),PTLON(4,15,50),
     1X3(101),Y3(101)
      DATA IX/531/,STDEV/1./,STDEVN/.5/,AMEAN/0./
      DATA TEST/.7/
      DATA JDIM/2/
      DATA SIGMA/1./
      DATA RNAV/.25/
      DATA RXTEND/.05/
      KFLAG=1
      DATA EXTEST /3.0/
      DATA RCUT,TSTCUT,JDIM /144.,.5,15/
      CALL READ(NUM)
      CALL NAV(NUM,RNAV,TEST)
      CALL GEORGE(NUM,NTAR,RCUT,RXTEND,EXTEST,TSTCUT,SIGMA,
     1JSET,PTLAT,PTLON,JDIM)
C
C
C    SUBROUTINE TO COMPUTE FINAL EMITTER TARGET JSET DATA
      WRITE(6,66)
      WRITE(6,202)
      WRITE(6,203)(K,K=1,18)
      DO 30 I=1,NTAR
      NSTA=NST(I)
      WRITE(6,204)I,(JSET(I,J),J=1,NSTA)
 30   CONTINUE
      K2=0
      WRITE(6,55)
      WRITE(6,53)
      DO 32 I=1,NTAR
      NSTA=NST(I)
      IF(NSTA.EQ.1) GO TO 32
      KI=JSET(I,1)
      WRITE(6,64) I,K2,KI,P11(KI),P12(KI),G1(KI),G2(KI)
      JSTA=JST(I)
      DO 31 J=2,JSTA
      K=JSET(I,J)
      WRITE(6,64) I,J,K,P11(K),P12(K),G1(K),G2(K)
 31   CONTINUE
 32   CONTINUE
      WRITE(6,55)
      WRITE(6,54)
      DO 35 I=1,NTAR
      NSTA=NST(I)
      IF(NSTA.EQ.1) GO TO 35
      KI=JSET(I,1)
      WRITE(6,65)I,K2,KI,T(KI),THTD(KI),TDTD(KI)
      JSTA=JST(I)
      DO 34 J=2,JSTA
      K=JSET(I,J)
      WRITE(6,65) I,J,K,T(K),THTD(K),TDTD(K),E(K),GATE(K)
 34   CONTINUE
 35   CONTINUE
C
      DO 37 I=1,NTAR
      WRITE(6,59)I
      NSTA=NST(I)
      WRITE(6,52)I
      IF(NSTA.EQ.1) GO TO 110
      JSTA=JST(I)
      DO 45 J=1,JSTA
      K=JSET(I,J)
```

```
      WRITE(6,51)(K,FREQ(K),PRF(K),PW(K),THETAD(K),THTD(K),
     1SLAD(K),SLOD(K))
 45   CONTINUE
      IF(ABS(TLAD(I)).LE.1E-6) GO TO 46
      KF=JSET(I,JSTA)
      WRITE(6,68)THTD1(KF),THTD(KF)
      WRITE(6,70) TLAD(I),TLOD(I)
      IF(NSTA.EQ.JSTA) GO TO 37
      KF=JSET(I,NSTA)
      WRITE(6,71) YTD(KF),XTD(KF)
      GO TO 37
 46   WRITE(6,205)
      GO TO 37
 110  K=JSET(I,1)
      WRITE(6,67)K,FREQ(K),PRF(K),PW(K),THETAD(K),
     1SLAD(K),SLOD(K)
      WRITE(6,200)
 37   CONTINUE
C
 51   FORMAT(20X,I3,F7.1,F6.1,F5.2,4F10.4)
 52   FORMAT(      20X, 'FILTERED AND SMOOTHED EMITTER DATA',
     1' CORRELATED TO TARGET NUMBER ',I2,///, 22X, 'K', 2X,
     2'FREQ', 3X, 'PRF', 3X, 'PW',4X, 'THETAD', 5X, 'THTD',
     36X, 'SLAD', 6X, 'SLOD',/)
 53   FORMAT( 23X,'I', 3X, 'J', 3X, 'K', 6X, 'P11(K)',8X,
     1'P12(K)', 6X, 'G1(K)', 5X, 'G2(K)',/)
 54   FORMAT( //, 23X, 'I', 3X, 'J', 3X, 'K', 3X, 'T(K)',4X,
     1'THTD(K)', 3X, 'TDTD(K)', 3X, 'E(K)',5X, 'GATE(K)',/)
 55   FORMAT('1',29X, 'KALMAN FILTER PARAMETERS FOR ANGLE',
     1' FILTER', //)
 59   FORMAT('1',//////,40X, 'TARGET NUMBER ',I2,//)
 64   FORMAT(20X,3I4,F15.4,F13.4,2F10.4)
 65   FORMAT(20X,3I4,F9.3,F10.4,2F9.4,F11.4)
 66   FORMAT('1',///,20X,'FINAL JSET DATA',//)
 67   FORMAT(20X,I3,F7.1,F6.1,F5.2,F10.4,10X,2F10.4)
 68   FORMAT( //,22X,'SMOOTHED INITIAL BEARING ANGLE =',
     1F10.5, ' N', //, 24X, 'FILTERED FINAL BEARING ANGLE',
     2' =', F10.5, ' W', //)
 70   FORMAT( //, 30X, 'VECTOR METHOD SOLUTION OF',
     1' EMITTER LOCATION',//, 36X, 'EMITTER LATITUDE =',
     2F10.5,' N',//, 35X, 'EMITTER LONGITUDE =', F10.5,' W')
 71   FORMAT( //, 25X, 'EXTENDED KALMAN FILTER SOLUTION OF',
     1' EMITTER LOCATION',//, 36X, 'EMITTER LATITUDE =',
     2F10.5,' N',//, 35X, 'EMITTER LONGITUDE =', F10.5,' W')
 200  FORMAT(//, 40X, 'SINGLE LINE BEARING',//)
 202  FORMAT(///,35X,'LOB NUMBER ASSIGNED TO TARGET I',//)
 203  FORMAT(26X,18I3,//)
 204  FORMAT(20X,I3, 3X, 32I3)
 205  FORMAT(///,30X, '* THE LINES OF BEARING DO NOT CROSS',
     1'  *',/, 30X, '* THEREFORE NO SOLUTION IS POSSIBLE. ',
     2'*')
      STOP
      END
```

```
C     ........................................................
C
C     SUBROUTINE NAV(NUM,RNAV,TEST)
C
C     SUBROUTINE TO FILTER AND SMOOTH NOISY AIRCRAFT
C     NAVIGATION DATA
C
C     LIST OF VARIABLES
C
C     A11
C     A12
C     A21
C     A22    - SMOOTHING FILTER GAINS
C     ELAT   - LATITUDE FILTER ERROR TERM
C     ELAD1
C     ELAD2  - LATITUDE SMOOTHING FILTER ERROR TERM
C     ELON   - LONGITUDE FILTER ERROR TERM
C     ELON1
C     ELON2  - LONGITUDE SMOOTHING FILTER ERROR TERM
C     LEG1   - SUBSCRIPT CORRESPONDING TO FIRST NAV FIX IN A
C              LEG
C     LEG2   - LAST NAV FIX IN A LEG
C     LW     - WORK VECTOR FOR MINV
C     MW     - WORK VECTOR FOR MINV
C     PIN    - MINV ARGUMENT
C     PIN11
C     PIN12
C     PIN22  - INVERSE OF ERROR COVARIANCE MATRIX
C     Q11
C     Q12
C     Q22    - VARIANCE OF SYSTEM NOISE
C     SLAD   - AIRCRAFT LATITUDE
C     SLATD  - PREDICTED AIRCRAFT LATITUDE ESTIMATE
C     SLOND  - PREDICTED AIRCRAFT LONGITUDE ESTIMATE
C     SLOD   - AIRCRAFT LONGITUDE
C     SG1
C     SG2    - KALMAN FILTER GAIN
C     SP11
C     SP12
C     SP22   - ERROR COVARIANCE TERM - (K+1|K)
C     SPKK11
C     SPKK12
C     SPKK22- ERROR COVARIANCE TERM - (K|K)
C     TT     - TIME INCREMENT DIVIDED BY W
C     VELED  - AIRCRAFT VELOCITY EAST IN DEGREES
C     VELEDS- SMOOTHED AIRCRAFT VELOCITY EAST
C     VELEM  - AIRCRAFT VELOCITY EAST IN KNOTS
C     VELND  - AIRCRAFT VELOCITY NORTH IN DEGREES
C     VELNDS- SMOOTHED AIRCRAFT VELOCITY NORTH
C     VELNM  - AIRCRAFT VELCCITY NORTH IN KNOTS
C     NLEG   - NUMBER OF LEGS
C     RNAV   - VARIANCE OF MEASUREMENT NOISE
C
C     ........................................................
C


      SUBROUTINE NAV(NUM,RNAV,TEST)
C
      COMMON ACLAD(100),ACLAMD(100),ACLAR(100),ACLOD(100),
     1ACLOMD(100),ACLOR(100),ALT(100),BRNG(100),BRNGD(100),
     2E(100),FREQ(100),G1(100),G2(100),GATE(100),HDG(100),
     3HDGD(100),MODEN(100),MODET(100),NST(100),P11(100),
     4P12(100),P22(100),PITCH(100),PRF(100),PW(100),
     5ROLL(100),SLA(100),SLADSM(100),SLO(100),SLODSM(100),
     5T(100),TIMEN(100),TIMET(100),TDTD(100),THTD(100),
     6THTD1(100),THETA(100),THETAD(100),TLAD(100),TLOD(100),
     7VEL(100),VELE(100),VELN(100),XTD(100),YTD(100),
     8D11(100),JST(100)
      DIMENSION A11(100),A12(100),A21(100),A22(100),
     1ELAT(100),ELAD1(100),ELAD2(100),ELON(100),ELON1(100),
     2ELON2(100),LEG1(50),LEG2(50),LW(2),MW(2),PIN(2,2),
```

```
     3PIN11(100),PIN12(100),PIN22(100),Q11(100),Q12(100),
     4Q22(100),SLAD(100),SLATD(100),SLOND(100),SLOD(100)
     5,SG1(100),SG2(100),SP11(100),SP12(100),SP22(100),
     6SPKK11(100),SPKK12(100),SPKK22(100),TT(100),VELED(100)
     7,VELEDS(100),VELEM(100),VELND(100),VELNDS(100),
     8VELNM(100)
C
      DATA PIRAD/57.29578/
C
C   PROGRAM TO FILTER NOISY MEASURED  LATITUDE AND LONGITUDE
C
C   DIVIDE THE FLIGHT TRACK INTO LEGS FOR FILTERING
C
      L=1
      LEG1(1)=1
      DO 1 K=2,NUM
      KK=K-1
      TKM1=TIMET(KK)
      T(K)=TIMET(K)-TKM1
      IF(T(K).LE.120.0) GO TO 1
      LEG2(L)=KK
      LEG1(L+1)=K
      L=L+1
 1    CONTINUE
      LEG2(L)=NUM
      NLEG=L
C
C    START OF KALMAN FILTER PREDICTION PROBLEM
C
C   INITALIZE KALMAN FILTER
C
      DO 100 L=1,NLEG
      LEG2L=LEG2(L)
      LEG1L=LEG1(L)
      KI=LEG1L
      ELON(KI)=0.0
      ELAT(KI)=0.0
      T(KI)=0.0
      SG1(KI)=0.0
      SG2(KI)=0.0
      SPKK11(KI)=1.
      SPKK12(KI)=0.
      SPKK22(KI)=1.
      SP11(KI)=1.
      SP12(KI)=0.
      SP22(KI)=1.
      SLAD(KI)=ACLAD(KI)
      SLATD(KI)=ACLAD(KI)
      SLA(KI)=ACLAR(KI)
      VELND(KI)=(ACLAD(KI+1  )-ACLAD(KI))/T(KI+1)
      SLOND(KI)=ACLOD(KI)
      VELNM(KI)=VELND(KI)*216000.
      SLOD(KI)=ACLOD(KI)
      VELED(KI)=((ACLOD(KI+1)-ACLOD(KI))/T(KI+1))*COS(SLA(KI
      VELEM(KI)=VELED(KI)*216000.
C
C   START OF KALMAN FILTER RECURSION EQUATIONS
C
      LG1P1=LEG1L+1
      DO 6 K=LG1P1,LEG2L
      KK=K-1
      TT(K)=T(K)/1000.0
      Q11(K)=TT(K)**4/4.0
      Q12(K)=TT(K)**3/2.0
      Q22(K)=TT(K)**2
C
C   COMPUTE KALMAN FILTER GAINS
C
      SP11(K)=SPKK11(KK)+(2.0*SPKK12(KK)+SPKK22(KK)*T(K))*
     1T(K)+Q11(K)
      SP12(K)=SPKK12(KK)+SPKK22(KK)*T(K)+Q12(K)
      SP22(K)=SPKK22(KK)+Q22(K)
```

```
      SG1(K)=SP11(K)/(SP11(K)+RNAV*T(K)/3600.)
      SG2(K)=SP12(K)/(SP11(K)+RNAV*T(K)/3600.)
      SPKK11(K)=SP11(K)*(1.0-SG1(K))
      SPKK12(K)=SP12(K)*(1.0-SG1(K))
      SPKK22(K)=SP22(K)-SP12(K)*SG2(K)
C
C   FILTER LATTITUDE
C
      IFLAG=1
 700  SLATD(K)=SLAD(KK)+VELND(KK)*T(K)
      ELAT(K)=ACLAD(K)-SLATD(K)
C
C   TEST FOR EXCESS SYSTEM NOISE
C
      IF(ABS(ELAT(K)).LT.TEST) GO TO 800
C
C   THE DATA POINT ACLAD(K) IS INVALID, SO IT IS DISCARDED
C
      IF(IFLAG.EQ.2) GO TO 800
      ACLAD(KK)=SLATD(KK)
      ELAT(KK)=0.
      SLAD(KK)=SLATD(KK)
      VELND(KK)=VELND(KK-1)
      VELNM(KK)=VELNM(KK-1)
      SLA(KK)=SLAD(KK)/PIRAD
      IFLAG=2
      GO TO 700
 800  IFLAG=1
C
C   THE DATA POINT ACLAD(K) IS VALID, SO PROCEED
C
      SLAD(K)=SLATD(K)+SG1(K)*ELAT(K)
      VELND(K)=VELND(KK)+SG2(K)*ELAT(K)
      VELNM(K)=VELND(K)*216000.
      SLA(K)=SLAD(K)/PIRAD
C
C   FILTER LONGITUDE
C
 900  SLOND(K)=SLOD(KK)+VELED(KK)*T(K)
      ELON(K)=(ACLOD(K)-SLOND(K))*COS(SLA(K))
C
C   TEST FOR EXCESS SYSTEM NOISE
C
      IF(ABS(ELON(K)).LT.TEST) GO TO 1000
C
C   THE DATA POINT ACLOD(K) IS INVALID, SO IT IS DISCARDED
C
      IF(IFLAG.EQ.2) GO TO 1000
      ACLOD(KK)=SLOND(KK)
      ELON(KK)=0.
      SLOD(KK)=SLOND(KK)
      VELED(KK)=VELED(KK-1)
      VELEM(KK)=VELEM(KK-1)
      IFLAG=2
      GO TO 900
 1000 IFLAG=1
C
C   THE DATA POINT ACLOD(K) IS VALID, SO PROCEED
C
      SLOD(K)=SLOND(K)+SG1(K)*ELON(K)
      VELED(K)=(VELED(KK)+SG2(K)*ELON(K))*COS(SLA(K))
 6    VELEM(K)=VELED(K)*216000.
 100  CONTINUE
C
C   START OF FIXED INTERVAL SMOOTHING EQUATIONS
C
      DO 13 L=1,NLEG
      LEG2L=LEG2(L)
      LEG1L=LEG1(L)
      N=LEG2L-LEG1L
      IF(N.LE.3) GO TO 11
C
```

```
C   INITALIZE SMOOTHING FILTER
C
      SLADSM(LEG2L)=SLAD(LEG2L)
      VELNDS(LEG2L)=VELND(LEG2L)
      SLODSM(LEG2L)=SLOD(LEG2L)
      VELEDS(LEG2L)=VELED(LEG2L)
C
C   COMPUTE SMOOTHING FILTER GAINS
C
      DO 10 I=1,N
      K=LEG2L-I
      KK=K+1
      PIN(1,1)=SP11(K)
      PIN(1,2)=SP12(K)
      PIN(2,1)=SP12(K)
      PIN(2,2)=SP22(K)
      CALL MINV(PIN,2,DET,LW,MW)
      PIN11(K)=PIN(1,1)
      PIN12(K)=PIN(1,2)
      PIN22(K)=PIN(2,2)
      A11(K)=SPKK11(K)*PIN11(K)+SPKK12(K)*(PIN11(K)*T(K)+
     1PIN12(K))
      A12(K)=SPKK11(K)*PIN12(K)+SPKK12(K)*(PIN12(K)*T(K)+
     1PIN22(K))
      A21(K)=SPKK12(K)*PIN11(K)+SPKK22(K)*(PIN11(K)*T(K)+
     1PIN12(K))
      A22(K)=SPKK12(K)*PIN12(K)+SPKK22(K)*(PIN12(K)*T(K)+
     1PIN22(K))
C
C   SMOOTH LATITUDE ESTIMATES
C
      ELAD1(K)=SLADSM(KK)-SLATD(KK)
      ELAD2(K)=VELNDS(KK)-VELND(KK)
      SLADSM(K)=SLAD(K)+A11(K)*ELAD1(K)+A12(K)*ELAD2(K)
      VELNDS(K)=VELND(K)+A21(K)*ELAD1(K)+A22(K)*ELAD2(K)
      VELNDS(K)=VELND(K)+(A21(K)+A22(K))*ELAD1(K)
      SLA(K)=SLADSM(K)/PIRAD
C
C   SMOOTH LONGITUDE ESTIMATES
C
      ELON1(K)=(SLODSM(KK)-SLOND(KK))*COS(SLA(K))
      ELON2(K)=(VELEDS(KK)-VELED(KK))*COS(SLA(K))
      SLODSM(K)=SLOD(K)+A11(K)*ELON1(K)+A12(K)*ELON2(K)
      VELEDS(K)=VELED(K)+A21(K)*ELON1(K)+A22(K)*ELON2(K)
      SLO(K)=SLODSM(K)/PIRAD
 10   CONTINUE
      GO TO 13
C
C   TO ANY LEGS WITH 3 OR LESS POINTS, ASSIGN THE DATA VALUES
C   AS THE FILTERED AND SMOOTHED VALUES FOR THAT LEG
C
 11   DO 12 J=LEG1L,LEG2L
      SLADSM(J)=SLAD(J)
      SLA(J)=SLAD(J)/PIRAD
      VELNDS(J)=0.
      SLODSM(J)=SLOD(J)
      SLO(J)=SLOD(J)/PIRAD
 12   VELEDS(J)=0.
 13   CONTINUE
      WRITE(6,52)
      WRITE(6,53)
      WRITE(6,50) (K,SG1(K),SG2(K),SP11(K),SP12(K),SP22(K),
     1T(K),K=1,NUM)
      WRITE(6,52)
      WRITE(6,54)
      WRITE(6,51)(K,VELND(K),ELAT(K),SLATD(K),VELED(K),
     1ELON(K),SLOND(K),K=1,NUM)
 50   FORMAT( 24X, I4, 5F9.5, F9.2)
 51   FORMAT( 24X, I4, 2F9.5, F11.5, 2F9.5, F11.5)
 52   FORMAT('1',//////,38X, 'NAVIGATION DATA FILTER',
     1' PARAMETERS',//)
 53   FORMAT(27X, 'K',4X,'SG1', 6X, 'SG2', 6X, 'SP11', 5X,
```

```
     1'SP12', 5X, 'SP22', 7X, 'T',//)
54    FORMAT( 27X, 'K',3X,'VELND', 5X, 'ELAT', 7X, 'SLATD',
     14X, 'VELED', 5X, 'ELON', 5X, 'SLOND', //)
      RETURN
      END
```

```
C        ..................................................................
C
C         SUBROUTINE GEORGE(NUM,NTAR,RCUT,RXTEND,EXTEST,TSTCUT,
C        1SIGMA,JSET,PTLAT,PTLON,JDIM)
C
C     THIS FORTRAN PROGRAM IS DESIGNED TO ANALYZE AND SORT
C     ELECTRONIC EMITTER PARAMETERS AND AIRCRAFT NAVIGATION
C     DATA, TO FILTER EMITTER DATA USING KALMAN FILTER TECH-
C     NIQUES TO MINIMIZE BEARING ANGLE-OF-ARRIVAL MEASUREMENT
C     NOISE, TO SMOOTH INITIAL UNFILTERED BEARING ANGLES,
C     AND TO PREDICT EMITTER LOCATIONS USING VECTOR
C     METHODS
C
C        LIST OF VARIABLES NOT IN COMMON BLOCK
C
C        NJSET  - DATA POINTS TO BE ASSOCIATED TO A TARGET
C        TDTD1  - SMOOTHED BEARING RATE
C        TPTD   - THETAD(K+1|K)
C        TT     - VARIANCE OF SYSTEM NOISE
C        W11
C        W12
C        W21
C        W22    - SMOOTHING FILTER GAINS
C        X3     - X COORDINATE OF ERROR ELLIPSE
C        Y3     - Y COORDINATE OF ERROR ELLIPSE
C        SMOTH1
C        SMOTH2
C        SMOTH3
C        SMOTH4- INTERMEDIATE TERMS IN SMOOTHING COMPUTATIONS
C        DELFRE- CARRIER FREQUENCY TEST
C        DELPRF- PULSE REPITION FREQUENCY TEST
C        NTAR  - NUMBER OF TARGETS
C        RCUT   - VARIANCE OF DF BEARING MEASUREMENT ERROR
C        RXTEND- VARIANCE OF MEASUREMENT NOISE IN EXTEND
C        EXTEST- MULTIPLIER FOR TEST TO SWITCH TO EXTEND
C        TSTCUT- MULTIPLIER FOR BEARING CORRELATION TEST
C        SIGMA - MULTIPLIER TO VARY SIZE OF ERROR ELLIPSE AS
C                DEEINED BY POINTS
C
C
C        ..................................................................
C


         SUBROUTINE GEORGE(NUM,NTAR,RCUT,RXTEND,EXTEST,TSTCUT,
        1SIGMA,JSET,PTLAT,PTLON,JDIM)
C
         COMMON ACLAD(100),ACLAMD(100),ACLAR(100),ACLOD(100),
        1ACLOMD(100),ACLOR(100),ALT(100),BRNG(100),BRNGD(100),
        2E(100),FREQ(100),G1(100),G2(100),GATE(100),HDG(100),
        3HDGD(100),MODEN(100),MODET(100),NST(100),P11(100),
        4P12(100),P22(100),PITCH(100),PRF(100),PW(100),
        5ROLL(100),SLA(100),SLAD(100),SLO(100),SLOD(100),
        5T(100),TIMEN(100),TIMET(100),TDTD(100),THTD(100),
        6THTD1(100),THETA(100),THETAD(100),TLAD(100),TLOD(100),
        7VEL(100),VELE(100),VELN(100),XTD(100),YTD(100),
        8D11(100),JST(100)
         DIMENSION JSET(JDIM,50),NJSET(100),PTLAT(4,JDIM,50),
        1PTLON(4,JDIM,50),Q11(100),Q12(100),Q22(100),
        2TDTD1(100),TPTD(100),TT(100),W11(100),W12(100),
        3W21(100),W22(100),X3(101),Y3(101)
C
         DATA PIRAD/57.29578/
C
C     PROGRAM TO SORT EMITTER TARGET DATA AND ESTIMATE NUMBER
C     OF DISTINCT EMITTER TARGETS
C     DATA IS INITIALLY SORTED BY FREQUENCY AND PRF
C
         CUTERR=3.5*SQRT(RCUT)
         DO 1 I=1,NUM
   1     NJSET(I)=I
         NF=NUM
         DO 6 I=1,NUM
```

```
  K=NJSET(1)
  JSET(I,1)=K
  NSORT=NF
  NF=0
  NJ=1
  DO 5 J=2,NSORT
  KK=NJSET(J)
  DELFRE=FREQ(K)-FREQ(KK)
  DELPRF=PRF(K)-PRF(KK)
  IF(ABS(DELFRE).LE.30.0.AND.ABS(DELPRF).LE.10.) GO TO 4
  IF(ABS(DELFRE).GT.30.0) GO TO 3
  IF(PRF(K).EQ.0.0.OR.PRF(KK).EQ.0.0) GO TO 4
  DO 2 L=2,2
  RK=L*PRF(KK)
  TK=PRF(KK)/FLOAT(L)
  SK=PRF(K)
  CK=ABS(RK-SK)
  DK=ABS(TK-SK)
  FK=L*10.0
  IF(CK.LE.FK.OR.DK.LE.FK) GO TO 4
  CONTINUE
  NF=NF+1
  NJSET(NF)=KK
  GO TO 5
  NJ=NJ+1
  JSET(I,NJ)=KK
  CONTINUE
  NST(I)=NJ
  IF(NF.LE.1) GO TO 7
  NTAR=I+1
  IF(NF.EQ.0) GO TO 8
  NTAR=NTAR+1
  JSET(NTAR,1)=NJSET(1)
  NST(NTAR)=1
  WRITE(6,202)
  WRITE(6,203)(K,K=1,18)
  DO 9 I=1,NTAR
  NSTA=NST(I)
  WRITE(6,204)I,(JSET(I,J),J=1,NSTA)
  CONTINUE

PROGRAM TO FILTER NOISY MEASURED BEARING ANGLE THETAD(K)
AND AIRCRAFT NAVIGATION DATA FOR EACH SUSPECTED EMITTER
TARGET OF SIMILAR FREQUENCY AND PRF

INITIALIZATION OF KALMAN FILTER EQUATION PARAMETERS

  IFLAG=1
  NTAR1=1
  NUMTAR=NTAR
  DO 27 I=NTAR1,NUMTAR
  NJ=0
  NSTA2=NST(I)
  NSTA=NST(I)
  IF(NSTA.EQ.1) GO TO 27
  KI=JSET(I,1)
  P11(KI)=10000.0
  P12(KI)=0.0
  P22(KI)=10000.0
  Q11(KI)=0.0
  Q12(KI)=0.0
  Q22(KI)=0.0
  D11(KI)=1.0
  W11(KI)=1.
  W12(KI)=0.
  W21(KI)=0.
  W22(KI)=1.
  G2(KI)=P12(KI)/(P11(KI)+RCUT)
  G1(KI)=P11(KI)/(P11(KI)+RCUT)
  THTD(KI)=THETAD(KI)
  THTD1(KI)=THETAD(KI)
```

```
      TDTD(KI)=VEL(KI)*SIN(BRNG(KI))*PIRAD/600000.0
      TDTD1(KI)=TDTD(KI)
      T(KI)=0.0
C
C   START OF KALMAN FILTER PREDICTION PROBLEM
C
      DO 23 J=2,NSTA2
 11   K=JSET(I,J)
      KK=JSET(I,J-1)
      TKM1=TIMET(KK)
      T(K)=TIMET(K)-TKM1
      TT(K)=T(K)/1000.0
      Q11(K)=TT(K)**4/4.0
      Q12(K)=TT(K)**3/2.0
      Q22(K)=TT(K)**2
C
C   START OF KALMAN FILTER RECURSION EQUATIONS
C
      P11(K)=P11(KK)*(1.0-G1(KK))+2.0*P12(KK)*T(K)-(P12(KK)*
     1G1(KK)+P11(KK)*G2(KK))*T(K)+(P22(KK)-P12(KK)*G2(KK))*
     2T(K)**2+Q11(K)
      P12(K)=P12(KK)*(1.0-G1(KK))+(P22(KK)-P12(KK)*G2(KK))*
     1T(K)+Q12(K)
      P22(K)=P22(KK)-P12(KK)*G2(KK)+Q22(K)
      G1(K)=P11(K)/(P11(K)+RCUT)
      G2(K)=P12(K)/(P11(K)+RCUT)
      TPTD(K)=THTD(KK)+TDTD(KK)*T(K)
 12   E(K)=THETAD(K)-TPTD(K)
      THTD(K)=TPTD(K)+G1(K)*E(K)
      TDTD(K)=TDTD(KK)+G2(K)*E(K)
C
C   CORRELATION GATING SCHEME TO ESTIMATE WHETHER FILTERED
C   BEARING ANGLE THTD(K) IS AN EMISSION FROM EMITTER TARGET
C   NTAR = I OR A SPURIOUS EMISSION
C
      GATE(K)=SQRT(P11(K)+RCUT)*TSTCUT
      IF(ABS(E(K)).LT.GATE(K)) GO TO 22
 13   IF(IFLAG.EQ.1) GO TO 14
      IF(IFLAG.EQ.2) GO TO 17
      GO TO 18
 14   IF(THETAD(KK).LT.10.0.AND.THETAD(K).GT.350.0) GO TO 15
      IF(THETAD(KK).GT.350.0.AND.THETAD(K).LT.10.0) GO TO 16
      GO TO 20
 15   THETAD(K)=THETAD(K)-360.0
      THETA(K)=THETA(K)-6.283186
      IFLAG=2
      GO TO 12
 16   THETAD(K)=THETAD(K)+360.0
      THETA(K)=THETA(K)+6.283186
      IFLAG=3
      GO TO 12
 17   THETAD(K)=THETAD(K)+360.0
      THETA(K)=THETA(K)+6.283186
      GO TO 19
 18   THETAD(K)=THETAD(K)-360.0
      THETA(K)=THETA(K)-6.283186
 19   IFLAG=1
 20   NJ=NJ+1
      JSET (NTAR+1,NJ)=K
      NST(NTAR+1)=NJ
C
C  THTD(K) IS A SPURIOUS BEARING LINE AND IS ASSIGNED TO A
C  NEW TARGET.
C
      NST(I)=NST(I)-1
      NSTA2=NST(I)
      IF(NSTA2.LT.J) GO TO 24
      DO 21 L=J,NSTA2
 21   JSET(I,L)=JSET(I,L+1)
      GO TO 11
 22   IFLAG=1
C
```

```
C    SMOOTHING EQUATIONS FOR FIRST BEARING LINE ESTIMATE
C
      SMOTH1=1.0-P11(KK)*(1.0-G1(KK))/RCUT
      SMOTH2=SMOTH1*T(K)
      SMOTH3=-P12(KK)*(1.0-G1(KK))/RCUT
      SMOTH4=1.0+SMOTH3*T(K)
      W11(K)=W11(KK)*SMOTH1+W12(KK)*SMOTH2
      W12(K)=W11(KK)*SMOTH3+W12(KK)* SMOTH4
      W21(K)=W21(KK)* SMOTH1+W22(KK)*SMOTH2
      W22(K)=W21(KK)*SMOTH3+W22(KK)*SMOTH4
      D11(K)=D11(KK)-W11(K)**2*(P11(KK)+RCUT)/RCUT**2
      THTD1(K)=THTD1(KK)+(W11(K)/RCUT)*E(K)
      TDTD1(K)=TDTD1(KK)+(W21(K)/RCUT)*E(K)
      JST(I)=J
      IF(P11(K).LT.(EXTEST*RCUT)) GO TO 25
 23   CONTINUE
C
C    FILTERED BEARING ANGLE THTD(K) IS CORRELATED TO EMITTER
C    TARGET NTAR = I
C
 24   IF(NSTA2.NE.NSTA) NTAR=NTAR+1
      IF(NSTA2.EQ.1) GO TO 27
C
C    PROGRAM TO COMPUTE TARGET POSITION
C
      KI=JSET(I,1)
      KF=JSET(I,NSTA2)
      CALL PREPAR (KI,KF,SLAD,SLOD,THTD1(KF),THTD(KF),
     1TLAD(I),TLOD(I))
      GO TO 27
C
C   PROCESSING SWITCHES TO  EXTENDED KALMAN FILTERING
C
 25   CALL POINTS(I,J,SIGMA,RCUT,D11,HDGD,JSET,P11,SLAD,
     1SLOD,THTD1,THTD,PTLAT,PTLON,JDIM,&27)
      DO 26 N=1,4
      X3(N)=PTLON(N,I,J)
 26   Y3(N)=PTLAT(N,I,J)
      CALL EXTEND(I,J,NSTA2,RXTEND,TSTCUT,JSET,NST,SLAD,
     1SLOD,T,THETA,THETAD,THTD1,THTD,TLAD,TLOD,XTD,YTD,X3,
     2Y3,JDIM)
      IF(NSTA2.NE.NSTA) NTAR=NTAR+1
 27   CONTINUE
      IF(NUMTAR.EQ.NTAR) RETURN
      NTAR1=NUMTAR+1
      GO TO 10
 202  FORMAT('1',35X,'LOB NUMBER ASSIGNED TO TARGET I',//)
 203  FORMAT(26X,18I3,//)
 204  FORMAT(20X,I3, 3X, 32I3)
      END
```

```
C
C     ..................................................................
C
C      SUBROUTINE EXTEND(I,J,NSTA,RXTEND,TSTCUT,JSET,NST,
C     1SLAD,SLOD,T,THETA,THETAD,THTD1,THTD,TLAD,TLOD,XTD,
C     2YTD,X3,Y3,JDIM)
C
C      SUBROUTINE TO COMPUTE EMITTER LOCATION USING EXTENDED
C      KALMAN FILTERING TECHNIQUES.
C
C      LIST OF VARIABLES
C
C         I        - TARGET NUMBER
C         J        - CUT NUMBER CORRELATED TO TARGET I
C         A        - SEMI-MAJOR AXIS OF ERROR ELLIPSE
C         C        - SEMI-MINOR AXIS OF ERROR ELLIPSE
C         ALPHA    - ANGLE OF ROTATION OF ERROR ELLIPSE
C         THETA    - VECTOR OF DF BEARINGS
C         SLAD     - VECTOR OF A/C LATITUDES IN DEGREES
C         SLA      - VECTOR OF A/C LATITUDES IN RADIANS
C         SLOD     - VECTOR OF A/C LONGITUDES
C         SLO      - VECTOR OF A/C LONGITUDES
C         NST      - VECTOR OF NUMBER OF CUTS IN EACH TARGET
C         RXTEND   - VARIANCE OF MEASUREMENT NOISE
C         TSTCUT   - VARIABLE USED TO VARY SIZE OF GATE
C         YT       - LATITUDE OF TARGET
C         YTD      - LATITUDE OF TARGET
C         TLAD     - LATITUDE OF TARGET
C         XT       - LONGITUDE OF TARGET
C         XTD      - LONGITUDE OF TARGET
C         TLOD     - LONGITUDE OF TARGET
C         AT1      - DISTANCE FROM TARGET TO A/C IN DEGREES
C         AT2      - DISTANCE FROM TARGET TO A/C IN DEGREES
C         TX       - BEARING FROM A/C TO TARGET
C         DMX/DM   - RATE OF CHANGE OF DF BEARING WITH RESPECT
C                    TO CHANGE OF LONGITUDE OF TARGET
C         DMY/DM   - RATE OF CHANGE OF DF BEARING WITH RESPECT
C                    TO CHANGE OF LATITUDE OF TARGET
C         GY       - KALMAN FILTER GAIN IN Y
C         GX       - KALMAN FILTER GAIN IN X
C         ER       - DF BEARING ERROR
C         NSTA     - NUMBER OF CUTS CORRELATED TO TARGET I
C         GATE     - TEST OF CORRELATION OF DF CUTS
C         P11      - VARIANCE OF ERROR IN LONGITUDE
C         P12      - COVARIANCE OF LATITUDE ERROR WITH
C                    LONGITUDE ERROR
C         P22      - VARIANCE OF ERROR IN LATITUDE
C         Q11      - COVARIANCE OF SYSTEM ERRORS
C         Q12      - COVARIANCE OF SYSTEM ERRORS
C         Q22      - COVARIANCE OF SYSTEM ERRORS
C         EP11
C         EP12
C         EP22    - POSITION ERROR COVARIANCE TERMS FOR LINEAR
C                   FILTERS
C         G1
C         G2      - LINEAR FILTER GAINS
C         XTDDOT  - XTD1(K+1|K)
C         XTD1    - ESTIMATE OF TARGET LONGITUDE
C         YTD1    - ESTIMATE OF TARGET LATITUDE
C         YTDDOT- YTD1(K+1|K)
C         EX      - LONGITUDE ERROR
C         EY      - LATITUDE ERROR
C
C     ..................................................................
C


       SUBROUTINE EXTEND(I,J,NSTA,RXTEND,TSTCUT,JSET,NST,
      1SLAD,SLOD,T,THETA,THETAD,THTD1,THTD,TLAD,TLOD,XTD,
      2YTD,X3,Y3,JDIM)
C
       DIMENSION P11(80),P12(80),P22(80),XT(80),XTD(80),YT(80
      1YTD(80),SLA(80),SLAD(80),SLO(80),SLOD(80),THETA(80),
```

```
     2NST(80),ER(80),TX(80),DMX(80),DMY(80),GX(80),
     3GY(80),TLAD(30),TLOD(30),Q11(80),Q12(80),Q22(80),
     4T(1),JSET(JDIM,50),TT(80),GATE(80),THETAD(1),EP11(80),
     5EP12(80),EP22(80),G1(80),G2(80),XTD1(80),XTDDOT(80),
     6XTDHAT(80),YTD1(30),YTDDOT(80),YTDHAT(80),EX(80),
     7EY(80),THTD1(1),THTD(1),X3(4),Y3(4),Z(4),XX(101),
     8YY(101)
C
      DATA PIRAD/57.29578/
C
C    EXTENDED KALMAN FILTER INITIALIZATION
C
      WRITE(6,102)J,I
      K1=JSET(I,1)
      KI=JSET(I,J)
C
      CALL PREPAR (K1,KI,SLAD,SLOD,THTD1(KI),THTD(KI),
     1TLAD(I),TLOD(I))
C
C   TLAD, TLOD IS THE CURRENT ESTIMATE OF THE TARGET
C   POSITION.
C
C
C   X3,Y3 ARE THE LOCATIONS OF THE INTERSECTIONS OF THE
C   EDGES OF THE TWO ERROR CONES.
C
      TLA=TLAD(I)/PIRAD
      DELX=(X3(1)-X3(2))*COS(TLA)
      DELY=Y3(1)-Y3(2)
      ALPHA1=ATAN2(DELX,DELY)
      ALPHA2=ALPHA1-1.5737963
      ALPHAD=ALPHA1*PIRAD
C
C   ALPHAD IS THE ANGLE OF ROTATION OF THE ELLIPSE
C
      DELX=(TLOD(I)-X3(2))*COS(TLA)
      DELY=TLAD(I)-Y3(2)
      A=SQRT(DELX**2+DELY**2)
C
C   A IS THE SEMI-MAJOR AXIS
C
      DO 19 K=3,4
      DELX=(TLOD(I)-X3(K))*COS(TLA)
      DELY=TLAD(I)-Y3(K)
      BETA=ATAN2(DELX,DELY)
      GAMMA=ALPHA2-BETA
 19   Z(K)=SQRT(DELX**2+DELY**2)*COS(GAMMA)
      C=(ABS(Z(3))+ABS(Z(4)))/2.0
C
C   C IS THE SEMI-MINOR AXIS
C
      WRITE(6,103) ALPHAD,A,C
C
C   INITIALIZE THE KALMAN FILTERS
C
      WRITE(6,56)
      YTD(KI)=TLAD(I)
      XTD(KI)=TLOD(I)
      XT(KI)=XTD(KI)/PIRAD
      YT(KI)=YTD(KI)/PIRAD
      SLA(KI)=SLAD(KI)/PIRAD
      SLO(KI)=SLOD(KI)/PIRAD
      CA=COS(ALPHA1)
      SA=SIN(ALPHA1)
      P11(KI)=(A*SA)**2+(C*CA)**2
      P12(KI)=SA*CA*(A**2-C**2)
      P22(KI)=(A*CA)**2+(C*SA)**2
      AT1=(XT(KI)-SLO(KI))*COS(YT(KI))
      AT2=YT(KI)-SLA(KI)
      TX(KI)=ATAN2(AT1,AT2)
      ER(KI)=THETA(KI)-TX(KI)
      DM=(YTD(KI)-SLAD(KI))**2+(XTD(KI)-SLOD(KI))**2
```

```
     1*(COS(YT(KI)))**2
      DMX(KI)=(YTD(KI)-SLAD(KI))*COS(YT(KI))/DM
      DMY(KI)=-(XTD(KI)-SLOD(KI))*((YTD(KI)-SLAD(KI))*
     1SIN(YT(KI))+COS(YT(KI)))/DM
      DG=P11(KI)*DMX(KI)**2+2.0*P12(KI)*DMX(KI)*DMY(KI)
     1+P22(KI)*DMY(KI)**2+RXTEND
      GX(KI)=(P11(KI)*DMX(KI)+P12(KI)*DMY(KI))/DG
      GY(KI)=(P12(KI)*DMX(KI)+P22(KI)*DMY(KI))/DG
      EP11(KI)=P11(KI)
      EP12(KI)=P12(KI)
      EP22(KI)=P22(KI)
      G1(KI)=EP11(KI)/(EP11(KI)+RXTEND)
      G2(KI)=EP12(KI)/(EP11(KI)+RXTEND)
      EX(KI)=0.0
      EY(KI)=0.0
      XTDDOT(KI)=.001
      XTD1(KI)=XTD(KI)+GX(KI)*ER(KI)
      YTDDOT(KI)=.001
      YTD1(KI)=YTD(KI)+GY(KI)*ER(KI)
C
C     START OF KALMAN FILTER PREDICTION PROBLEM
C
C    COMPUTE GAINS FOR LINEARIZED FILTER
C
      NSTA=NST(I)
      JP1=J+1
      DO 12 JJ=JP1,NSTA
 20   K=JSET(I,JJ)
      KK=JSET(I,JJ-1)
      SLA(K)=SLAD(K)/PIRAD
      SLO(K)=SLOD(K)/PIRAD
      TT(K)=T(K)/1E3
      Q11(K)=TT(K)**4/4.0
      Q12(K)=TT(K)**3/2.0
      Q22(K)=TT(K)**2
C
C     START OF EXTENDED KALMAN FILTER RECURSION EQUATIONS
C
      P11(K)=P11(KK)*(1.0-GX(KK)*DMX(KK))-P12(KK)*GX(KK)*
     1DMY(KK)+Q11(K)
      P12(K)=P12(KK)*(1.0-GX(KK)*DMX(KK))-P22(KK)*GX(KK)*
     1DMY(KK)+Q12(K)
      P22(K)=P22(KK)*(1.0-GY(KK)*DMY(KK))-P12(KK)*GY(KK)*
     1DMX(KK)+Q22(K)
      DM=(YTD(KK)-SLAD(K))**2+(XTD(KK)-SLOD(K))**2
     1*(COS(YT(KK)))**2
      DMX(K)=(YTD(KK)-SLAD(K))*COS(YT(KK))/DM
      DMY(K)=-(XTD(KK)-SLOD(K))*((YTD(KK)-SLAD(K))*
     1SIN(YT(KK))+COS(YT(KK)))/DM
      DG=P11(K)*DMX(K)**2+2.0*P12(K)*DMX(K)*DMY(K)+
     1P22(K)*DMY(K)**2+RXTEND
      GX(K)=(P11(K)*DMX(K)+P12(K)*DMY(K))/DG
      GY(K)=(P12(K)*DMX(K)+P22(K)*DMY(K))/DG
      AT1=(XT(KK)-SLO(K))*COS(YT(KK))
      AT2=YT(KK)-SLA(K)
      TX(K)=ATAN2(AT1,AT2)
 1    ER(K)=THETA(K)-TX(K)
C
C     CORRELATION GATING SCHEME TO ESTIMATE WHETHER FILTERED
C     BEARING ANGLE THTD(K) IS AN EMISSION FROM EMITTER TARGET
C     NTAR = I OR A SPURIOUS EMISSION
C
      GATE(K)=SQRT(P11(K)+RXTEND)*TSTCUT
      IF(ABS(ER(K)).LT.GATE(K)) GO TO 11
 2    IF(IFLAG.EQ.1) GO TO 3
      IF(IFLAG.EQ.2) GO TO 6
      GO TO 7
 3    IF(THETAD(KK).LT.10.0.AND.THETAD(K).GT.350.0) GO TO 4
      IF(THETAD(KK).GT.350.0.AND.THETAD(K).LT.10.0) GO TO 5
      GO TO 9
 4    THETA(K)=THETA(K)-6.283186
      IFLAG=2
```

```
      GO TO 1
 5    THETA(K)=THETA(K)+6.283186
      IFLAG=3
      GO TO 1
 6    THETA(K)=THETA(K)+6.283186
      GO TO 8
 7    THETA(K)=THETA(K)-6.283186
 8    IFLAG=1
 9    NJ=NJ+1
      JSET (NTAR+1,NJ)=K
      NST(NTAR+1)=NJ
C
C   THTD(K) IS A SPURIOUS BEARING LINE AND IS ASSIGNED TO A
C   NEW TARGET.
C
      NST(I)=NST(I)-1
      NSTA=NST(I)
      IF(NSTA.LT.JJ) GO TO 13
      DO 10 L=JJ,NSTA2
 10   JSET(I,L)=JSET(I,L+1)
      GO TO 20
 11   IFLAG=1
C
C   COMPUTE GAINS FOR LINEAR FILTERS
C
      EP11(K)=EP11(KK)*(1.0-G1(KK))+2.0*EP12(KK)*T(K)-
     1(EP12(KK)*G1(KK)+EP11(KK)*G2(KK))*T(K)+(EP22(KK)-
     2EP12(KK)*G2(KK))*T(K)**2+Q11(K)
      EP12(K)=EP12(KK)*(1.0-G1(KK))+(EP22(KK)-EP12(KK)*
     2G2(KK))*T(K)+Q12(K)
      EP22(K)=EP22(KK)-EP12(KK)*G2(KK)+Q22(K)
      G1(K)=EP11(K)/(EP11(K)+RXTEND)
      G2(K)=EP12(K)/(EP11(K)+RXTEND)
C
C   FIND BEST ESTIMATES OF TARGET LONGITUDE, XTD1, AND TARGET
C   LATITUDE, YTD1
C
      YTDHAT(K)=YTD(KK)+YTDDOT(KK)*T(K)
      EY(K)=YTD1(KK)-YTDHAT(K)
      YTD(K)=YTDHAT(K)+G1(K)*EY(K)
      YTDDOT(K)=YTDDOT(KK)+G2(K)*EY(K)
      YTD1(K)=YTD(K)+GY(K)*ER(K)
      YT(K)=YTD1(K)/PIRAD
      XTDHAT(K)=XTD(KK)+XTDDOT(KK)*T(K)
      EX(K)=(XTD1(KK)-XTDHAT(K))*COS(YT(K))
      XTD(K)=XTDHAT(K)+G1(K)*EX(K)
      XTDDOT(K)=(XTDDOT(KK)+G2(K)*EX(K))*COS(YT(K))
      XTD1(K)=XTD(K)+GX(K)*ER(K)
      XT(K)=XTD1(K)/PIRAD
 12   CONTINUE
 13   WRITE(6,51)
      DO 14 JJ=J,NSTA
      K=JSET(I,JJ)
 14   WRITE(6,52)K,P11(K),P12(K),P22(K),GX(K),GY(K)
      WRITE(6,50)
      DO 15 JJ=J,NSTA
      K=JSET(I,JJ)
 15   WRITE(6,53)K,DMX(K),DMY(K),TX(K),ER(K),XTD(K),YTD(K)
      WRITE(6,56)
      WRITE(6,54)
      DO 16 JJ=J,NSTA
      K=JSET(I,JJ)
 16   WRITE(6,52)K,EP11(K),EP12(K),EP22(K),G1(K),G2(K)
      WRITE(6,55)
      DO 17 JJ=J,NSTA
      K=JSET(I,JJ)
 17   WRITE(6,53)K,EX(K),EY(K),XTDDOT(K),YTDDOT(K),XTD1(K),
     1YTD1(K)
C
 50   FORMAT( //, 22X, 'K', 4X, 'DMX', 6X, 'DMY', 6X, 'TX',
     17X, 'ER', 8X, 'XTD', 7X, 'YTD',/)
 51   FORMAT( //, 22X, 'K', 5X, 'P11', 8X, 'P12', 8X,'P22',
```

```
     17X, 'GX', 6X, 'GY',/)
52    FORMAT(20X,I3,3E11.3,3F8.3)
53    FORMAT(20X,I3,4F9.4,F11.4,F10.4)
54    FORMAT(//, 22X, 'K', 4X, 'EP11',7X,'EP12', 7X, 'EP22',
     17X, 'G1', 6X, 'G2',/)
55    FORMAT( //,22X,'K', 5X,'EX', 7X,'EY', 4X,'XTDDOT', 3X,
     1'YTDDOT', 6X, 'XTD1', 6X, 'YTD1',/)
56    FORMAT('1', //////, 34X, 'EXTENDED KALMAN FILTER ',
     1'PARAMETERS',//)
102   FORMAT( '1', //////, 25X, 'THE EXTENDED KALMAN FILTER'
     1' IS INITIATED WITH THE ',/, 25X, 'FOLLOWING ELLIPSE',
     2 ' FOR CUT NUMBER', I3, ' OF TARGET', I3)
103   FORMAT(//, 25X, 'THE ANGLE BETWEEN THE MAJOR AXIS AND'
     2' THE MERIDIAN',/, 25X, 'THROUGH THE CENTER OF THE ',
     3'ELLIPSE IS ', F7.3,' DEGREES.',//, 25X, 'THE LENGTH O
     4'THE SEMI-MAJOR AXIS IS ',F7.3,' DEGREES.',//, 25X,
     5'THE LENGTH OF THE SEMI-MINOR AXIS IS ',F7.3,' DEGRE',
     6'ES.',//)
      RETURN
      END
```

```
C     ..............................................
C
C     SUBROUTINE PREPARE
C
C     SUBROUTINE TO ESTABLISH THE VECTOR CROSS PRODUCT
C     MATRIX FOR SUBROUTINE POSIT
C
C     ..............................................


      SUBROUTINE PREPAR (KI,K,SLAD,SLOD,THTD1,THTD,TLAD,
     1TLOD)
C
      DIMENSION SLAD(1),SLOD(1),ACLAT(2),ACLON(2),THD(2)
C
      DATA PIRAD/57#29578/
      THT1=THTD1
      THT=THTD
C
C  DETERMINE DIRECTION OF TRACK
C
      DELLAD=SLAD(K) -SLAD(KI)
      DELLON=SLOD(K) -SLOD(KI)
      IF(DELLAD.EQ.0.0.AND.DELLON.EQ.0.0) GO TO 37
      TRACK=90.-ATAN2(DELLAD,DELLON)*PIRAD
      IF(TRACK.LT.0.0) TRACK=TRACK+360.
      IF(THT.LT.TRACK.AND.THT1.GE.TRACK) GO TO 37
      IF(THT1.LT.TRACK.AND.THT.GE.TRACK) GO TO 37
C
C  DETERMINE IF TARGET IS LEFT OR RIGHT OF TRACK
C
      M=1
      N=2
      IF(TRACK.LE.180) GO TO 38
      IF(THT1.LT.TRACK.AND.THT1.GE.(TRACK-180.)) GO TO 40
      GO TO 39
 38   IF(THT1.GT.TRACK.AND.THT1.LE.(TRACK+180.)) GO TO 39
      GO TO 40
C
C  TARGET IS TO RIGHT OF TRACK
C
 39   IF(THT1.GT.270.AND.THT.LT.90.) THT=THT+360.
      IF(THT.GT.270.AND.THT1.LT.90.) THT1=THT1+360.
      IF(THT1.GT.THT) GO TO 37
      M=2
      N=1
      GO TO 41
C
C  TARGET IS TO LEFT OF TRACK
C
 40   IF(THT1.GT.270.AND.THT.LT.90.) THT=THT+360.
      IF(THT.GT.270.AND.THT1.LT.90.) THT1=THT1+360.
      IF(THT.GT.THT1) GO TO 37
 41   ACLAT(M)=SLAD(KI)
      ACLAT(N)=SLAD(K)
      ACLON(M)=SLOD(KI)
      ACLON(N)=SLOD(K)
      THD(M)=THT1
      THD(N)=THT
      CALL POSIT(ACLAT,ACLON,THD,TLAD,TLOD)
      RETURN
C
C  BEARINGS DO NOT CROSS SO NO SOLUTION IS COMPUTED
C
 37   TLAD=0.0
      TLOD=0.0
      RETURN
C
      END
```

```
C     ........................................................
C
C     SUBROUTINE POSIT (SLA, SLO, THETA, TLA, TLO)
C
C     SUBROUTINE TO COMPUTE TARGET POSITION COORDINATES
C     USING VECTOR METHODS
C
C     DESCRIPTION OF CALLING ARGUMENTS
C
C     SLA   - AIRCRAFT LATITUDE
C     SLA   - AIRCRAFT LONGITUDE
C     THETA - BEARING ANGLES-OF-ARRIVAL
C     TLA   - TARGET LATITUDE
C     TLO   - TARGET LONGITUDE
C
C     ........................................................

      SUBROUTINE POSIT (SLA, SLO, THETA, TLA, TLO)
C
      DIMENSION A(2),B(2),C(2),SLA(2),SLO(2),THETA(2)
C
      DATA PIRAD/57.29578/
      DO 1 I=1,2
      PH=SLA(I)/PIRAD
      TH=SLO(I)/PIRAD
      OB=THETA(I)/PIRAD
      ST=SIN(TH)
      CT=COS(TH)
      SP=SIN(PH)
      CP=COS(PH)
      CO=COS(OB)
      SO=SIN(OB)
C
C  COMPUTE NORMAL TO BEARING PLANE
C
      DX=-SP*CO*CT-ST*SO
      DY=SO*CT-SP*CO*ST
      DZ=CP*CO
C
C  COMPUTE BEARING VECTORS
C
      X1=CP*CT
      Y1=CP*ST
      AA=Y1*DZ-SP*DY
      BB=SP*DX-X1*DZ
      CC=X1*DY-Y1*DX
      D=SQRT(AA**2+BB**2+CC**2)
      A(I)=AA/D
      B(I)=BB/D
      C(I)=CC/D
 1    CONTINUE
C
C  COMPUTE TARGET POSITION VECTOR IN (X,Y,Z) COORDINATES
C
      X1=B(1)*C(2)-C(1)*B(2)
      X2=C(1)*A(2)-A(1)*C(2)
      X3=A(1)*B(2)-B(1)*A(2)
      D=SQRT(X1**2+X2**2+X3**2)
      X1=X1/D
      X2=X2/D
      X3=X3/D
C
C  COMPUTE TARGET POSITION VECTOR IN (O,O) COORDINATES
C
      TLO=ATAN2(X2,X1)*PIRAD
      TLA=ATAN2(X3,SQRT(X1**2+X2**2))*PIRAD
C
      RETURN
      END
```

```
.................................................................

NE POINTS

NE TO LOCATE THE INTERSECTION OF THE CONES OF
SOCIATED WITH EACH OF BEARING AND DESCRIBED BY
RIANCE MATRICES OF THE ANGLE FILTER AND THE
G FILTER

.................................................................

NE POINTS(I,J,SIGMA,RCUT,D11,HDGD,JSET,P11,
),THTD1,THTD,PTLAT,PTLON,JDIM,*)

N ACLAT(2),ACLON(2),D11(1),HDGD(1),JSET(JDIM,
),PTLAT(4,JDIM,1),PTLON(4,JDIM,1),SLAD(1),
THD(2),THTD1(1),THTD(1)

AD/57.29578/

,J)
D1(K)
(K)
).GE.3.*RCUT) GO TO 5
(ABS(D11(K)))*SIGMA
P11(K))*SIGMA
102)
101) K,THT,P11(K),P1,THT1,D11(K),D1

SURE THAT THE TWO BEARING LINES DO NOT
T THE SAME POINT

I,1)
LAD(K) -SLAD(KI)
LOD(K) -SLOD(KI)
).EQ.0.0.AND.DELLON.EQ.0.0) GO TO 6

SUBSCRIPTS SUCH THAT PTLAT(1), PTLON(1) IS
HE FLIGHT PATH THAN PTLAT(2),PTLON(2).


LE.HDGD(K)) GO TO 1


=SLAD(KI)
=SLOD(KI)
=SLAD(K)
=SLOD(K)


,LE.1.) GO TO 4

 EDGES OF THE ERROR ELLIPSES DO NOT CROSS, SO
 GREATER THAN 1, REDUCE IT TO 1 AND COMPUTE
SECTION POINT.


104)

OF INTERSECTION OF THTD1 - D1 WITH THTD + P1

HT1-D1
HT+P1
).LE.THD(2).AND.M.EQ.1) GO TO 2
).LE.THD(1).AND.M.EQ.2) GO TO 2
IT(ACLAT,ACLON,THD,TLAT,TLON)
I,J)=TLAT
I,J)=TLON

OF INTERSECTION OF THTD1 + D1 WITH THTD - P1
```

```
C
      THD(1)=THT1+D1
      THD(2)=THT-P1
      IF(THD(1).LE.THD(2).AND.M.EQ.1) GO TO 2
      IF(THD(2).LE.THD(1).AND.M.EQ.2) GO TO 2
      CALL POSIT(ACLAT,ACLON,THD,TLAT,TLON)
      PTLAT(N,I,J)=TLAT
      PTLON(N,I,J)=TLON
C
C   FIND POINT OF INTERSECTION OF THTD1 - D1 WITH THTD - P1
C
      THD(1)=THT1-D1
      THD(2)=THT-P1
      CALL POSIT(ACLAT,ACLON,THD,TLAT,TLON)
      PTLAT(3,I,J)=TLAT
      PTLON(3,I,J)=TLON
C
C   FIND POINT OF INTERSECTION OF THTD1 + D1 WITH THTD + P1
C
      THD(1)=THT1+D1
      THD(2)=THT+P1
      CALL POSIT(ACLAT,ACLON,THD,TLAT,TLON)
      PTLAT(4,I,J)=TLAT
      PTLON(4,I,J)=TLON
      RETURN
C
 4    WRITE(6,105)
      RETURN 1
 5    WRITE(6,103) P11(K),I,J
      RETURN 1
 6    WRITE(6,106) I
      RETURN 1
C
 101  FORMAT(I5,6F12.4)
 102  FORMAT('1', /, 4X, 'K', 5X, 'THTD(K)', 6X, 'P11(K)',
     18X, 'P1', 6X, 'THTD1(K)',6X, 'D11(K)', 8X, ' D1', /)
 103  FORMAT(//,5X, 'THE ERROR COVARIANCE IS ', F12.4, ' .',
     1'  A SOLUTION WOULD BE MEANINGLESS.  I=',I3,' J=',I3,/
 104  FORMAT(/, '        SIGMA=1.',/)
 105  FORMAT(//, 5X, 'THE TWO OUTSIDE BEARINGS DO NOT ',
     1'CROSS, SO NO SOLUTION IS POSSIBLE.',//)
 106  FORMAT(//, 5X, 'THE BEGINNING AND END OF THE TRACK ',
     1'CORRELATED WITH TRAGET ',I2, ' COINCIDE, SO NO SOL',
     2'UTION IS POSSIBLE',//)
      RETURN
      END
```

```
C     ...........................................................
C
C     SUBROUTINE PIC
C
C     SUBROUTINE TO PLOT THE DF CUTS, ERROR ELLIPSES
C     COMPUTED FROM THE ANGLE FILTER AND THE ERROR ELLIPSES
C     DESCRIBED BY THE COVARIANCE MATRIX OF THE EXTENDED
C     KALMAN FILTER
C
C     MODES
C
C     IFLAG=1  PLOTS THE DF CUTS CORRELATED TO TARGET I
C     IFLAG=2  PLOTS THE ERROR ELLIPSE DESCRIBED BY THE P11
C     AND D11 TERMS FROM THE ANGLE FILTERING ROUTINE
C     ASSOCIATED WITH CUT J OF TARGET I
C
C     THIS SUBROUTINE FIRST DETERMINES THE MAJOR DIRECTION
C     OF THE PLOT, PLOTS IT THE MAJOR DIRECTION OF THE PLOT
C     USING A MERCATOR PROJECTION
C
C     ...........................................................


      SUBROUTINE PIC(IFLAG,I,JJ,NST,JSET,SLAD,SLOD,TLAD,
     1TLOD,THETA,THTD,THTD1,P11,D11,HDGD,RCUT,JDIM,PTLAT,
     2PTLON,SIGMA,P12,P22,XTD1,YTD1)
C
      DIMENSION ACLAT(100),ACLON(100),A(4),B(4),D11(1),
     1FLAD(100),FLOD(100),HDGD(1),IT1(12),IT2(12),IT3(12),
     2IT4(13),JSET(JDIM,1),NST(1),NUMB(25),PTLAT(4,JDIM,1),
     3PTLON(4,JDIM,1),P11(1),SLAD(1),SLOD(1),THETA(1),
     4TLAD(1),TLOD(1),THTD(1),THTD1(1),XX(101),XZ(101),
     5YY(101),P12(1),P22(1),XTD1(1),YTD1(1),IT5(13)
C
      DATA IT1/'PLOT OF DF CUTS AND A/C NAVIGATION DATA '/
      DATA IT2/'                EDWARD H. MILLS                 '/
      DATA IT3/'                         NTAR =                 '/
      DATA IT4/'PLOT',' OF ','ERRO','R CO','VARI','ANCE',
     1'S OF',' SMO','OTHE','D BE','ARIN','G LI','NES '/
      DATA IT5/'PLOT',' OF ','ERRO','R CO','VARI','ANCE',
     1'S OF',' EXT','ENDE','D KA','LMAN',' FIL','TER '/
      DATA NUMB/'1','2','3','4','5','6','7','8','9','10',
     1'11','12','13','14','15','16','17','18','19','20',
     2'21','22','23','24','25'/
C
      DATA PIRAD/57.29578/
C
      NSTA=NST(I)
      IF(IFLAG.EQ.1) JJ=NSTA
      DO 1 J=1,NSTA
      K=JSET(I,J)
      ACLAT(J)=SLAD(K)
 1    ACLON(J)=SLOD(K)
      IF(IFLAG.EQ.2) GO TO 9
      IF(IFLAG.EQ.3) GO TO 41
      A(1)=TLAD(I)
      B(1)=TLOD(I)
      ALATS=SMALL2(ACLAT,NSTA,A,1)
      ALATH=HUGE2(ACLAT,NSTA,A,1)
      ALONS=SMALL2(ACLON,NSTA,B,1)
      ALONH=HUGE2(ACLON,NSTA,B,1)
      GO TO 12
 9    IF(NSTA.LE.3) GO TO 1000
      CALL POINTS(I,JJ,SIGMA,RCUT,D11,HDGD,JSET,P11,SLAD,
     1SLOD,THTD1,THTD,PTLAT,PTLON,JDIM,&1000)
      DO 10 N=1,4
      XX(N)=PTLON(N,I,JJ)
 10   YY(N)=PTLAT(N,I,JJ)
      GO TO 42
 41   K=JSET(I,JJ)
      CALL ELIPS7(P11(K),P12(K),P22(K),XTD1(K),YTD1(K),XX,
     1YY)
```

```
      N=101
 42   ALONS=SMALL2(ACLON,NSTA,XX,N)
      ALONH=HUGE2(ACLON,NSTA,XX,N)
      ALATS=SMALL2(ACLAT,NSTA,YY,N)
      ALATH=HUGE2(ACLAT,NSTA,YY,N)
C
C   ADAD=AIRCRAFT POSITION LATITUDE VARIATION IN DEGREES
C   ADOD=AIRCRAFT POSITION LONGITUDE VARIATION IN DEGREES
C
 12   ADAD=ABS(ALATH-ALATS)
      ADOD=ABS(ALONH-ALONS)
      ASLAR=((ALATH+ALATS)/2.)/PIRAD
      CSLA=COS(ASLAR)
      ADAD2=.75*ADAD
      IF(ADOD.GT.ADAD2) GO TO 21
C
C   ADAD IS GREATER THAN ADOD
C
C   PROGRAM TO SCALE DATA FOR NORTH LATITUDE AND WEST
C   LONGITUDE ONLY
C
C   COMPUTE X AND Y  SCALE INCREMENT VALUES DX AND DY
C
      DX=1.
      IF(ADAD.GT.8) DX=ADAD/8.
      IF(ADOD.GT.6) DX=ADOD/6.
      IF(ADOD.LE.3.AND.ADAD.LE.4) DX=.5
      IF(ADOD.LE.1.5.AND.ADAD.LE.2) DY=.25
      DY=DX
C
C   COMPUTE X AND Y AXIS INITIAL VALUES XMIN AND YMIN
C
C   LONGITUDE IS WEST(-) IN DEGREES
C
      ABSC=0.0
      MIN=ALONS-(DX+.5)
      XMIN=MIN
C
C   LATITUDE IS NORTH(+) IN DEGREES
C
      ORD=90.0
      MIN=ALATS-(DY+.5)
      YMIN=MIN
C
C    DRAW AXIS
C
      XORIG=0.0
      YORIG=0.0
      CDIV=1
      SDIV=CSLA
      LA=1
      LB=2
      LC=-7
      IT3(7)=NUMB(I)
      CALL PLOTS
      CALL PLOT(-3.,0.,-3)
      CALL PLOT(1.,0.,-3)
      CALL AXIS(XORIG,YORIG,'DEGREES LONGITUDE',-17,6.0,
     1ABSC,XMIN,DX,CDIV,SDIV)
      CALL AXIS(XORIG,YORIG,'DEGREES LATITUDE',-16,8.,ORD,
     1YMIN,DY,CDIV,SDIV)
      CALL SYMBOL(0.0,14.0,0.21,IT2,0.0,40)
      CALL SYMBOL(0.0,13.5,0.21,IT3,0.0,40)
C
C   SCALE DATA
C
      DY=DX*CSLA
      DO 2 N=1,NSTA
      XX(N)=(ACLON(N)-XMIN)/DX
  2   YY(N)=(ACLAT(N)-YMIN)/DY
C
C    DRAW NAV TRACK
```

```
C
      CALL LINE(XX,YY,NSTA,LA,LB)
C
      IF(IFLAG.EQ.2) GO TO 5
      IF(IFLAG.EQ.3) GO TO 43
      CALL SYMBOL(0.0,14.5,0.21,IT1,0.0,40)
C
C    PLOT OF CUTS TO FORM THEORETICAL EMMITTER LOCATION
C
      DO 4 J=1,NSTA
      DT=0.0
      K=JSET(I,J)
      CTH=COS(THETA(K))
      STH=SIN(THETA(K))
      DO 3 L=1,100
      LL=L
      FLAD(L)=YY(J)+DT*CTH
      FLOD(L)=XX(J)+DT*STH
      IF(FLAD(L).GT.8 .OR.FLAD(L).LT.0) GO TO 13
      IF(FLOD(L).GT.6. OR. FLOD(L).LT.0) GO TO 13
      DT=.07*L
 3    CONTINUE
 13   CALL LINE(FLOD,FLAD,LL,LA,LC)
 4    CONTINUE
C
C    SUBROUTINE TO PLOT SMOOTHED INITIAL BEARING LINE AND
C    KALMAN FILTERED FINAL BEARING LINE
C
C    SMOOTHED INITIAL BEARING LINE (THTD1)
C
      KI=JSET(I,1)
      KF=JSET(I,NSTA)
      THT1=THTD1(KF)/PIRAD
      FX=XX(1)+8.*SIN(THT1)
      FY=YY(1)+8.*COS(THT1)
      SX=XX(1)
      SY=YY(1)
      CALL PLOT(SX,SY,3)
      CALL PLOT(FX,FY,2)
C
C    KALMAN FILTERED FINAL BEARING LINE (THTD)
C
      THTF=THTD(KF)/PIRAD
      FY=YY(NSTA)+8.*COS(THTF)
      FX=XX(NSTA)+8.*SIN(THTF)
      SX=XX(NSTA)
      SY=YY(NSTA)
      CALL PLOT(SX,SY,3)
      CALL PLOT(FX,FY,2)
C
      GO TO 8
C
C    PLOT THE ELLIPSE FORMED BY THE P11 TERMS OF THE
C    ERROR COVARIANCE MATRICES.
C
 5    CALL SYMBOL(0.0,15.0,0.21,IT4,0.0,52)
      FLOOT=JJ
      CALL NUMBER(5.25, 7.,.14,FLOOT,90.,-1)
      KI=JSET(I,1)
      K=JSET(I,JJ)
      DO 11 N=1,4
      XX(N)=PTLON(N,I,JJ)
 11   YY(N)=PTLAT(N,I,JJ)
      CALL ELIPS6(KI,K,SLAD,SLOD,THTD1(K),THTD(K),D11(K),
     1P11(K),XX,YY,A1,B1,ALPHA1,TLAD(I),TLOD(I))
 20   DO 6 K=1,101
      XX(K)=(XX(K)-XMIN)/DX
 6    YY(K)=(YY(K)-YMIN)/DY
      CALL LINE(XX,YY,101,1,1)
C
C    PLOT THE FILTERED FIRST AND CURRENT FINAL CUTS.
C
```

```
      K=JSET(I,JJ)
      THT1=THTD1(K)/PIRAD
      SX=(ACLAT(1)-XMIN)/DX
      SY=(ACLON(1)-YMIN) /DY
      FX=SX+8.*COS(THT1)
      FY=SY+8.*SIN(THT1)
      CALL PLOT(SX,SY,3)
      CALL PLOT(FX,FY,2)
      THT=THTD(K)/PIRAD
      SX=(ACLAT(J)-XMIN)/DX
      SY=(ACLON(J)-YMIN)/DY
      FX=SX+8.*COS(THT)
      FY=SY+8.*SIN(THT)
      CALL PLOT(SX,SY,3)
      CALL PLOT(FX,FY,2)
C
      GO TO 8
C
C   PLOT THE ELLIPSE FORMED BY THE ERROR COVARIANCE TERMS
C   OF THE EXTENDED KALMAN FILTER.
C
 43   CALL SYMBOL(0.0,15.0,0.21,IT5,0.0,52)
      FLOOT=JJ
      CALL NUMBER(5.25, 7.,.14,FLOOT,90.,-1)
      K=JSET(I,JJ)
      CALL ELIPS7(P11(K),P12(K),P22(K),XTD1(K),YTD1(K),XX,
     1YY)
      DO 44 K=1,101
      XX(K)=(XX(K)-XMIN)/DX
 44   YY(K)=(YY(K)-YMIN)/DY
      CALL LINE(XX,YY,101,1,1)
C
 8    CALL PLOT(-3.,18.,-3)
      CALL PLOT(1.75,0.,-3)
      CALL PLOTE
      RETURN
C
 21   DY=1.
C
C  ADOD IS GREATER THAN ADAD
C
      IF(ADOD.GE.8) DY=ADOD/8.
      IF(ADAD.GT.6) DY=ADAD/6.
      IF(ADOD.LE.4.AND.ADAD.LE.3.) DY=.5
      IF(ADOD.LE.2.AND.ADAD.LE.1.5) DY=.25
C   LONGITUDE IS WEST(-) IN DEGREES
      DX=DY
      ABSC=90.0
      MIN=ALONS-(DY+.5)
      YMIN=MIN
      IF(DY.LT.(.5)) YMIN=ALONS-DY
C   LATITUDE IS NORTH(+) IN DEGREES
      ORD=0.0
      MIN=ALATS-.5
      XMIN=MIN
      IF(ABS(XMIN-ALATS).GT..9) XMIN=XMIN+1.
      IF(DX.LT.(.5)) XMIN=ALATS
      XMAX=XMIN+5.*DX
      DX=-DX
C
C    DRAW AXIS
C
      XORIG=0.0
      YORIG=0.0
      CDIV=CSLA
      SDIV=1.
      LA=1
      LB=2
      LC=-7
      IT3(7)=NUMB(I)
      CALL PLOTS
      CALL PLOT(-3.,0.,-3)
```

```
      CALL PLOT(2.,0.,-3)
      CALL AXIS(XORIG,YORIG,'DEGREES LATITUDE',-16,6.0,ORD,
     1XMAX,DX,CDIV,SDIV)
      CALL AXIS(XORIG,YORIG,'DEGREES LONGITUDE',-17,8.0,
     1ABSC,YMIN,DY,CDIV,SDIV)
      CALL PLOT(XORIG,YORIG,3)
      CALL PLOT(0.0,YORIG,2)
      CALL PLOT(0.0,0.0,2)
      CALL SYMBOL(0.0,14.0,0.21,IT2,0.0,40)
      CALL SYMBOL(0.0,13.5,0.21,IT3,0.0,40)
      CALL PLOT(XORIG,0.,-3)
C
C   SCALE DATA
C
      DX=DX*CSLA
      DO 22 N=1,NSTA
      XX(N)=(ACLAT(N)-XMIN)/DX
 22   YY(N)=(ACLON(N)-YMIN)/DY
C
C    DRAW NAV TRACK
C
      CALL LINE(XX,YY,NSTA,LA,LB)
C
      IF(IFLAG.EQ.2) GO TO 27
      IF(IFLAG.EQ.3) GO TO 45
      ORIGX=XORIG-.75
      ORIGY=YORIG+.3
      CALL SYMBOL(-ORIGX,ORIGY,.14,IT1,0.,40)
      FLOOT=I
      CALL NUMBER(-.75,7.,.14,FLOOT,90.,-1)
C
C   PLOT OF CUTS TO FORM THEORETICAL EMMITTER LOCATION
C
      DO 26 J=1,NSTA
      DT=0.0
      K=JSET(I,J)
      CTH=COS(THETA(K))
      STH=SIN(THETA(K))
      DO 23 L=1,100
      LL=L
      FLAD(L)=XX(J)-DT*CTH
      FLOD(L)=YY(J)+DT*STH
      IF(FLAD(L).GT.0.OR.FLAD(L).LT.-6) GO TO 24
      IF(FLOD(L).GT. 8. OR. FLOD(L).LT.0) GO TO 24
      DT=.07*L
 23   CONTINUE
 24   CALL LINE(FLAD,FLOD,LL,LA,LC)
 26   CONTINUE
C
C   SUBROUTINE TO PLOT SMOOTHED INITIAL BEARING LINE AND
C   KALMAN FILTERED FINAL BEARING LINE
C
C   SMOOTHED INITIAL BEARING LINE (THTD1)
C
      KF=JSET(I,NSTA)
      THT1=THTD1(KF)/PIRAD
      FX=XX(1)-8.*COS(THT1)
      FY=YY(1)+8.*SIN(THT1)
      SX=XX(1)
      SY=YY(1)
      CALL PLOT(SX,SY,3)
      CALL PLOT(FX,FY,2)
      WRITE(6,101) SX,SY
C
C   KALMAN FILTERED FINAL BEARING LINE (THTD)
C
      THTF=THTD(KF)/PIRAD
      FX=XX(NSTA)-8.*COS(THTF)
      FY=YY(NSTA)+8.*SIN(THTF)
      SX=XX(NSTA)
      SY=YY(NSTA)
      CALL PLOT(SX,SY,3)
```

```
      CALL PLOT(FX.FY,2)
      WRITE(6.101) SX,SY
      GO TO 30
C
C   PLOT THE ELLIPSE FORMED BY THE P11 TERMS OF THE
C   ERROR COVARIANCE MATRICES.
C
 27   ORIGY=YORIG+.3
      CALL SYMBOL(-XORIG,ORIGY,0.14,IT4,0.,52)
      FLOOT=JJ
      CALL NUMBER(-.75,7.,0.14,FLOOT,90.,-1)
      KI=JSET(I,1)
      K=JSET(I,JJ)
      DO 40 N=1,4
      XX(N)=PTLON(N,I,JJ)
 40   YY(N)=PTLAT(N,I,JJ)
      CALL ELIPS6(KI,K,SLAD,SLOD,THTD1(K),THTD(K),D11(K),
     1P11(K),XX,YY,A1,B1,ALPHA1,TLAD(I),TLOD(I))
      WRITE(6,101)(XX(J),YY(J),J=1,10)
      WRITE(6,101) XMIN,YMIN
      DO 29 J=1,101
      XZ(J)=(YY(J)-XMIN)/DX
 29   YY(J)=(XX(J)-YMIN)/DY
      WRITE(6,101)(XZ(J),YY(J),J=1,10)
      CALL LINE(XZ,YY,101,1,1)
C
C   PLOT THE FILTERED FIRST AND CURRENT FINAL CUTS.
C
      THT1=THTD1(K)/PIRAD
      SX=(ACLAT(1)-XMIN)/DX
      SY=(ACLON(1)-YMIN)/DY
      FX=SX-7.*COS(THT1)
      FY=SY+7.*SIN(THT1)
      CALL PLOT(SX,SY,3)
      CALL PLOT(FX,FY,2)
      THT=THTD(K)/PIRAD
      WRITE(6,100) K,THT
      SX=(ACLAT(JJ)-XMIN)/DX
      SY=(ACLON(JJ)-YMIN)/DY
      FX=SX-7.*COS(THT)
      FY=SY+7.*SIN(THT)
      CALL PLOT(SX,SY,3)
      CALL PLOT(FX,FY,2)
      GO TO 30
C
C   PLOT THE ELLIPSE FORMED BY THE ERROR COVARIANCE TERMS
C   OF THE EXTENDED KALMAN FILTER.
C
 45   ORIGY=YORIG+.3
      CALL SYMBOL(-XORIG,ORIGY,0.14,IT5,0.,52)
      FLOOT=JJ
      CALL NUMBER(-.75, 7.,.14,FLOOT,90.,-1)
      K=JSET(I,JJ)
      CALL ELIPS7(P11(K),P12(K),P22(K),XTD1(K),YTD1(K),XX,
     1YY)
      DO 46 J=1,101
      XZ(J)=(YY(J)-XMIN)/DX
 46   YY(J)=(XX(J)-YMIN)/DY
      CALL LINE(XZ,YY,101,1,1)
C
C  MARK THE KNOWN POSITION OF THE TARGET
C
 30   IF(I.GT.2) GO TO 47
      IF(I.EQ.2) GO TO 36
      ATLAD=33.24055
      ATLON=-117.4169
      GO TO 37
 36   ATLAD=32.78222
      ATLON=-117.2244
 37   SX1=(ATLAD-XMIN)/DX
      SY1=(ATLON-YMIN)/DY
      SX=SX1-1.
```

```
      FX=SX1+1.
      SY=SY1-1.
      FY=SY1+1.
      CALL PLOT(SX,SY1,3)
      CALL PLOT(FX,SY1,2)
      CALL PLOT(SX1,SY,3)
      CALL PLOT(SX1,FY,2)
 47   CALL PLOT(-12.,18.,-3)
      CALL PLOT(1.75,0.,-3)
      CALL PLOTE
 100  FORMAT(I5,2F12.6)
 101  FORMAT(2F12.6,/)
 102  FORMAT('1',I3)
 105  FORMAT(2F12.3,3I5)
 1000 RETURN
      END
C
C
C     ............................................
C
C     SUBROUTINE AXIS
C
C     SUBROUTINE TO COMPUTE, DRAW AND LABEL THE AXES FOR A
C     MERCATOR PROJECTION IN THE NORTH WEST HEMISPHERE
C
C     ............................................


      SUBROUTINE AXIS (XB,YB,BCD,NC,SIZE,THETA,YMIN,DY,CDIV,
     1SDIV)
      DIMENSION BCD(1)
      ZING=1.0
      IF(NC)1,2,2
    1 ZING = -1.0
    2 NAC=IABS(NC)
      TH=THETA*.0174533
      CTH=COS(TH)/CDIV
      STH=SIN(TH)/SDIV
      N = SIZE+0.50
      IF(THETA.EQ.90.AND.CDIV.EQ.1) N=SIZE*SDIV
      IF(THETA.EQ.0.AND.SDIV.EQ.1) N=SIZE*CDIV
      TN=N
      X=XB
      Y=YB
      XA = X - 0.1 * ZING * STH
      YA = Y + 0.1 * ZING * CTH
      CALL PLOT (XA,YA,3)
      DO 20 I=1,N
      CALL PLOT (XB,YB,2)
      XC=XB + CTH
      YC=YB+STH
      CALL PLOT (XC,YC,2)
      XA=XA+CTH
      YA=YA + STH
      CALL PLOT(XA,YA,2)
      XB=XC
 20   YB=YC
      YA=Y-0.250
      IF(ABS(YMIN).GE.100.)YA=Y-.375
      IF(ABS(YMIN).GE.100.AND.YMIN.LT.0.0) YA=Y-.50
      IF(THETA.EQ.90.0) GO TO 22
      IF(THETA.EQ.0.0)GO TO 24
 22   XA=X + 0.250
      GO TO 25
 24   XA=X-.250
      IF(ABS(YMIN).GE.100.)XA=X-.375
      IF(ABS(YMIN).GE.100.AND.YMIN.LT.0.0) XA=X-.50
 25   WRITE(6,61)XA,YA
      ABSV=YMIN
      DO 30 I=1,N
      CALL NUMBER(XA,YA,0.14,ABSV,THETA,2)
      ABSV=ABSV+DY
```

```
      XA=XA+CTH
      YA=YA+STH
30    CONTINUE
      TNC=NAC+7
      CTH=CTH*CDIV
      STH=STH*SDIV
      XA=X+(SIZE /2.0-.06 *TNC)*CTH - (-.07 + ZING*.42)*  STH
      YA=Y+(SIZE /2.0-.06 *TNC)*STH + (-.07 + ZING*.42)*  CTH
      CALL SYMBOL(XA,YA,0.14,BCD,THETA,NAC)
      WRITE(6,62)XB,YB
60    FORMAT('0    ABSV=',F10.5)
61    FORMAT('0   XA=',F10.5,'   YA=',F10.5)
62    FORMAT(/,3X,'XB=',F10.5,2X,'YB=',F10.5,/)
50    RETURN
      END

      FUNCTION SMALL2(A,NSTA,B,N)
      DIMENSION A(50),B(50)
      SMALL2=A(1)
      DO 1 I=2,NSTA
      IF(SMALL2.LE.A(I)) GO TO 1
      SMALL2=A(I)
1     CONTINUE
      DO 2 I=1,N
      IF(SMALL2.LE.B(I)) GO TO 2
      SMALL2=B(I)
2     CONTINUE
      RETURN
      END

      FUNCTION HUGE2(A,NSTA,B,N)
      DIMENSION A(50),B(50)
      HUGE2=A(1)
      DO 1 I=2,NSTA
      IF(HUGE2.GE.A(I)) GO TO 1
      HUGE2=A(I)
1     CONTINUE
      DO 2 I=1,N
      IF(HUGE2.GE.B(I)) GO TO 2
      HUGE2=B(I)
2     CONTINUE
      RETURN
      END
```

```
C
C     ......................................................
C
C     SUBROUTINE ELIPS6
C
C     SUBROUTINE TO DESCRIBE AN ELLIPSE TO FIT THE FOUR
C     POINTS COMPUTED IN SUBROUTINE POINTS
C
C     ......................................................


      SUBROUTINE ELIPS6(KI,KC,SLAD,SLOD,THTD1,THTD,D11,P11,
     1X3,Y3,A1,B1,ALPHA1,TLAD,TLOD)
C
      DIMENSION SLAD(1),SLOD(1),X(101),X3(101),Y(101),
     1Y3(101),Z(4)
C
      DATA PIRAD/57.29578/
C
      CALL PREPAR (KI,KC,SLAD,SLOD,THTD1,THTD,TLAD,TLOD)
C
C  TLAD, TLOD IS THE CURRENT ESTIMATE OF THE TARGET
C  POSITION.
C
C  X3,Y3 ARE THE LOCATIONS OF THE INTERSECTIONS OF THE
C  EDGES OF THE TWO ERROR CONES.
C
      DELX=X3(1)-X3(2)
      DELY=Y3(1)-Y3(2)
      ALPHA1=ATAN2(DELX,DELY)
      ALPHA2=ALPHA1-1.5737963
      ALPHAD=ALPHA1*PIRAD
C
C  ALPHAD IS THE ANGLE OF ROTATION OF THE ELLIPSE
C
      DELX=TLOD-X3(2)
      DELY=TLAD-Y3(2)
      A1=SQRT(DELX**2+DELY**2)
C
C  A1 IS THE SEMI-MAJOR AXIS
C
      DO 4 K=3,4
      DELX=TLOD-X3(K)
      DELY=TLAD-Y3(K)
      BETA=ATAN2(DELX,DELY)
      GAMMA=ALPHA2-BETA
 4    Z(K)=SQRT(DELX**2+DELY**2)*COS(GAMMA)
      B1=(ABS(Z(3))+ABS(Z(4)))/2.0
C
C  B1 IS THE SEMI-MINOR AXIS
C
      WRITE(6,103) ALPHAD,A1,B1
C
      EPS=A1/25.
      Y(1)=-A1
      Y(101)=-A1
      AA=A1** 2
      BB=B1**2
      DO 1 K=2,51
      KK=K-1
      Y(K)=Y(KK)+EPS
 1    Y(102-K)=Y(K)
      DO 2 K=1,51
      CC=ABS(BB*(1.-(Y(K)**2)/AA))
      X(K)=SQRT(CC)
 2    X(102-K)=-X(K)
C
C  ROTATE THE ELLIPSE BY ALPHAD AND TRANSLATE ITS CENTER TO
C  TLOD,TLAD.
C
      CA=COS(ALPHA1)
      SA=SIN(ALPHA1)
      DO 3 K=1,101
```

```
      X3(K)=X(K)*CA+Y(K)*SA+TLOD
 3    Y3(K)=-X(K)*SA+Y(K)*CA+TLAD
      WRITE(6,101)X3(1),Y3(1),X3(50),Y3(50),X3(25),Y3(25),
     1X3(75),Y3(75)
C
 101  FORMAT(4F12.2)
 103  FORMAT(//,5X,'THE ANGLE BETWEEN THE MAJOR AXIS AND ',
     2'THE MERIDIAN',/,5X,'THROUGH THE CENTER OF THE ',
     3'ELLIPSE IS ',F7.3,' DEGREES.',//,5X,'THE LENGTH OF ',
     4'THE SEMI-MAJOR AXIS IS ',F7.3,' DEGREES.',//,5X,
     5'THE LENGTH OF THE SEMI-MINOR AXIS IS ',F7.3,' DEGRE',
     6'ES.',//)
      RETURN
      END
```

```
C     ...................................................................
C
C     SUBROUTINE ELIPS7
C
C     SUBROUTINE TO DESCRIBE THE ELLIPSE TO FIT THE ERROR
C     COVARIANCE TERMS IN THE EXTENDED KALMAN FILTER
C
C     ...................................................................


      SUBROUTINE ELIPS7(A,C,B,TLOD,TLAD,X3,Y3)
C
      DIMENSION X(101),Y(101),X3(101),Y3(101)
C
      DATA PIRAD/57.29578/
C
      AMIB=A-B
      IF(ABS(AMIB).LT.1E-8) GO TO 10
      ALPHAD=90.-.5*ATAN2((2.*C),AMIB)*PIRAD
      GO TO 11
 10   ALPHAD=0.0
 11   ALPHA1=ALPHAD/PIRAD
      CA=COS(ALPHA1)
      SA=SIN(ALPHA1)
      A2=ABS(A*SA**2+2.*C*SA*CA+B*CA**2)
      A1=SQRT(A2)
      B2=ABS(A*CA**2-2.*C*SA*CA+B*SA**2)
      B1=SQRT(B2)
C
C  ALPHAD IS THE ANGLE OF ROTATION OF THE ELLIPSE
C
C  A1 IS THE SEMI-MAJOR AXIS
C
C  B1 IS THE SEMI-MINOR AXIS
C
      WRITE(6,103) ALPHAD,A1,B1
C
      EPS=A1/25.
      Y(1)=-A1
      Y(101)=-A1
      BB=B2
      AA=A2
      DO 1 K=2,51
      KK=K-1
      Y(K)=Y(KK)+EPS
 1    Y(102-K)=Y(K)
      DO 2 K=1,51
      CC=ABS(BB*(1.-(Y(K)**2)/AA))
      X(K)=SQRT(CC)
 2    X(102-K)=-X(K)
C
C   ROTATE THE ELIPSE SUCH THAT AA IS PARALLEL TO THTD1 AND
C   TRANSLATE TO XZERO AND YZERO.
C
      DO 3 K=1,101
      X3(K)=X(K)*CA+Y(K)*SA+TLOD
 3    Y3(K)=-X(K)*SA+Y(K)*CA+TLAD
      DO 23 K=1,51
 23   WRITE(6,101)X3(K),Y3(K),X3(K+50),Y3(K+50)
C
 101  FORMAT(4F12.2)
 103  FORMAT(5X, 'THE ANGLE BETWEEN THE MAJOR AXIS AND THE '
     1'MERIDIAN THROUGH THE CENTER OF THE ELLIPSE IS ',F7.3,
     1' DEGREES',/, 5X, 'THE LENGTH OF THE SEMI-MAJOR AXIS '
     2'IS',F7.3,' DEGREES', /, 5X, 'THE LENGTH OF THE SEMI-'
     3'MINOR AXIS IS',F7.3,' DEGREES',/)
 104  FORMAT( /,5X,'LATTITUDE AND LONGITUDE OF', /, 3X,
     1'THTD + P11  THTD -P11  THTD1 - D11 THTD1 + D11', /,3X
     2'WITH THTD1  WITH THTD1  WITH THTD   WITH THTD', /)
      RETURN
      END
```

```
C     ......................................................
C
C     SUBROUTINE MONACO(NUM,IX,STDEV,STDEVN,AMEAN,KFLAG,NRUN
C
C     SUBROUTINE TO READ AIRCRAFT DATA AND ADD GAUSSIANLY
C     DISTRIBUTED RANDOM NOISE
C
C     LIST OF VARIABLES
C
C     IX     - INITIAL NUMBER FOR RANDOM NUMBER GENERATOR
C     STDEV  - STANDARD DEVIATION OF NOISE ADDED TO DF BEARIN
C     STDEVN- STANDARD DEVIATION OF NOISE ADDED TO NAVIGATIO
C     AMEAN  - MEAN OF ALL NOISE
C     KFLAG  - COUNTER FOR REPEATED MONTE CARLO RUNS
C     NRUN   - NUMBER OF RUNS DESIRED FOR MONTE CARLO
C              SIMULATION. MUST BE GREATER THAN OR EQUAL TO 2
C     AMEANT- MEAN OF DF BEARING NOISE
C     AMEANE- MEAN OF LONGITUDE NOISE
C     AMEANN- MEAN OF LATITUDE NOISE
C     VARIT  - VARIANCE OF BEARING NOISE
C     VARIE  - VARIANCE OF LONGITUDE NOISE
C     VARIN  - VARIANCE OF LATITUDE NOISE
C     PIRAD  - CONVERSION FACTOR 57.29578 DEGREES PER RADIAN
C
C     ......................................................
C


      SUBROUTINE MONACO(NUM,IX,STDEV,STDEVN,AMEAN,KFLAG,NRUN
C
      COMMON ACLAD(100),ACLAMD(100),ACLAR(100),ACLOD(100),
     1ACLOMD(100),ACLOR(100),ALT(100),BRNG(100),BRNGD(100),
     2E(100),FREQ(100),G1(100),G2(100),GATE(100),HDG(100),
     3HDGD(100),MODEN(100),MODET(100),NST(100),P11(100),
     4P12(100),P22(100),PITCH(100),PRF(100),PW(100),
     5ROLL(100),SLA(100),SLAD(100),SLO(100),SLOD(100),
     5T(100),TIMEN(100),TIMET(100),TDTD(100),THTD(100),
     6THTD1(100),THETA(100),THETAD(100),TLAD(100),TLOD(100),
     7VEL(100),VELE(100),VELN(100),XTD(100),YTD(100),
     8D11(100),JST(100)
C
      DATA AMEANT,AMEANE,AMEANN,VARIT,VARIE,VARIN/0.,0.,0.,
     10.,0.,0./
      DATA PIRAD/57.29578/
C
      IF(KFLAG.NE.1) GO TO 3
C
C    SUBROUTINE TO READ EMITTER TARGET AND AIRCRAFT
C    NAVIGATION DATA FROM CARD DATA DECK
C    DATA SEQUENCE MUST BE OF FORMAT TGT/NAV
C
      DO 1 I=1,100
      NUM=I-1
C
C    READ EMITTER TARGET DATA
C
      READ(5,48,END=8)TGT,TIMET(I),BRNGD(I),PRF(I),PW(I),
     1FREQ(I)
C
C    READ AIRCRAFT NAVIGATION DATA
C
      READ(5,48)HDGD(I),ACLAMD(I),ACLOMD(I),ALT(I),VELN(I),
     1VELE(I)
 1    CONTINUE
C
C    SUBROUTINE TO COMPUTE AIRCRAFT VELOCITY
C
 8    DO 2 I=1,NUM
      VELS=VELE(I)**2+VELN(I)**2
      VEL(I)=SQRT(VELS)
C
C    SUBROUTINE TO CHANGE ANGLES FROM DEGREES TO RADIANS
```

```
C
      HDG(I)=HDGD(I)/PIRAD
      BRNG(I)=BRNGD(I)/PIRAD
 2    CONTINUE
C
C   GENERATE RANDOM NOISE TO ADD TO KNOWN EMITTER BEARING
C   ANGLES OF ARRIVAL AND AIRCRAFT POSITION FIXES.
C
 3    IXE=5.*IX
      IXN=7*IX
      DO 4 I=1,NUM
      CALL GAUSS(IX,STDEV,AMEAN,V)
      AMEANT=AMEANT+V/NUM
      VARIT=VARIT+V**2/NUM
      THETAD(I)=BRNGD(I)+V
      THETA(I)=THETAD(I)/PIRAD
      IF(THETA(I).GT.6.283186) THETA(I)=THETA(I)-6.283186
      IF(THETAD(I).GT.360.0) THETAD(I)=THETAD(I)-360.0
      CALL GAUSS(IXE,STDEVN,AMEAN,V)
      AMEANE=AMEANE+V/NUM
      VARIE=VARIE+V**2/NUM
      ACLOD(I)=ACLOMD(I)+V/600.
      ACLOR(I)=ACLOD(I)/PIRAD
      CALL GAUSS(IXN,STDEVN,AMEAN,V)
      AMEANN=AMEANN+V/NUM
      VARIN=VARIN+V**2/NUM
      ACLAD(I)=ACLAMD(I)+V/600.
      ACLAR(I)=ACLAD(I)/PIRAD
 4    CONTINUE
      DEVNT=SQRT(VARIT)
      DEVNE=SQRT(VARIE)
      DEVNN=SQRT(VARIN)
      IF(KFLAG.EQ.NRUN) GO TO 6
      IF(KFLAG.NE.1) GO TO 7
      WRITE(6,201)
      WRITE(6,49)(I,TIMET(I),FREQ(I),PRF(I),PW(I),BRNGD(I),
     1V,THETAD(I),HDGD(I),ACLAMD(I),ACLOMD(I),ALT(I),
     2VELN(I),VELE(I),I=1,NUM)
      WRITE(6,50)
      WRITE(6,51)(ACLAMD(I),ACLAD(I),ACLOMD(I),ACLOD(I),
     1I=1,NUM)
 6    WRITE(6,202)AMEANT,DEVNT,AMEANE,DEVNE,AMEANN,DEVNN
 7    KFLAG=KFLAG+1
      RETURN
 48   FORMAT(6F11.5)
 49   FORMAT(' ',I3,2X,F5.1,2X,F6.1,2X,F5.1,2X,F4.2,2X,F9.5,
     12X,F8.5,2X,F9.5,2X,F5.1,2X,F8.5,2X,F10.5,2X,2F8.1,
     2F3.1)
 50   FORMAT(3X,'LATITUDE  NOISY LAT  LONGITUDE  NOISY ',
     1'LONGITUDE',/)
 51   FORMAT(4F11.5)
 201  FORMAT('1',36X,'LISTING OF EMITTER TARGET DATA AND ',
     1'AIRCRAFT NAVIGATION DATA',///,13X,'TARGET PARAMETERS'
     2,37X,'AIRCRAFT PARAMETERS',//,' JSET TIMET   FREQ    ',
     3' PRF     PW      BRNGD          V         THETAD      HDGD  ',
     4'  SLAD          SLOD           ALT      VELN    VELE',//)
 202  FORMAT( ///, 5X, 'NOISE ADDED TO BEARING ANGLES OF ',
     1'ARRIVAL',/,10X,'MEAN = ',F5.2,/,10X,'SIGMA = ',F5.2,
     2//,5X, 'NOISE ADDED TO LONGITUDE FIXES',/, 10X,'MEAN',
     3' = ',F5.2, /, 10X, 'SIGMA = ', F5.2, //, 5X,'NOISE ',
     4'ADDED TO LATITUDE FIXES', /, 10X, 'MEAN = ', F5.2, /,
     510X, 'SIGMA = ', F5.2,///)
      END
```

```
C     .....................................................
C
C     SUBROUTINE READ
C
C     SUBROUTINE TO READ ACTUAL AIRCRAFT PECM MISSION TAPES
C
C     .....................................................

      SUBROUTINE READ(NUM)
C
C   SUBROUTINE TO READ EMITTER TARGET AND AIRCRAFT
C   NAVIGATION DATA FROM CARD DATA DECK
C   DATA SEQUENCE MUST BE OF FORMAT TGT/NAV
C
C
C
      COMMON  ACLAD(100),ACLAMD(100),ACLAR(100),ACLOD(100),
     1ACLOMD(100),ACLOR(100),ALT(100),BRNG(100),BRNGD(100),
     2E(100),FREQ(100),G1(100),G2(100),GATE(100),HDG(100),
     3HDGD(100),MODEN(100),MODET(100),NST(100),P11(100),
     4P12(100),P22(100),PITCH(100),PRF(100),PW(100),
     5ROLL(100),SLA(100),SLAD(100),SLO(100),SLOD(100),
     5T(100),TIMEN(100),TIMET(100),TDTD(100),THTD(100),
     6THTD1(100),THETA(100),THETAD(100),TLAD(100),TLOD(100),
     7VEL(100),VELE(100),VELN(100),XTD(100),YTD(100),
     8D11(100),JST(100)
C
      DATA PIRAD/57.29578/
C
      WRITE(6,53)
      DO  1  I=1,100
      NUM=I-1
C   TYPE=11.0  EMITTER TARGET DATA
      READ(5,51,END=2)TGT,TIMET(I),BRNG(I),PRF(I),MODET(I),
     1PW(I),FREQ(I)
C   TYPE=7.0   AIRCRAFT NAVIGATION DATA
      READ(5,52) NAV,TIMEN(I),MODEN(I),ALT(I),ACLAR(I),
     1ACLOR(I)
      READ(5,56)HDG(I),VELE(I),VELN(I),ROLL(I),PITCH(I)
      WRITE(6,54)I,TIMET(I),FREQ(I),BRNG(I),PRF(I),PW(I),
     1MODET(I)
      WRITE(6,55)TIMEN(I),HDG(I),ALT(I),ACLAR(I),ACLOR(I),
     1VELN(I),VELE(I),ROLL(I),PITCH(I),MODEN(I)
C
C   SUBROUTINE TO COMPUTE AIRCRAFT VELOCITY
C
      VELS=VELE(I)**2+VELN(I)**2
      VEL(I)=SQRT(VELS)
  1   CONTINUE
C
C   SUBROUTINE TO CHANGE ANGLES AND LATITUDE/LONGITUDE
C   FROM RADIANS TO DEGREES + TENTHS OF DEGREES
C
 2    DO 5 J=1,NUM
      HDGD(J)=HDG(J)*PIRAD
      BRNGD(J)=BRNG(J)*PIRAD
      ACLAD(J)=ACLAR(J)*PIRAD
      ACLOD(J)=ACLOR(J)*PIRAD
      ACLAMD(J)=ACLAD(J)
      ACLOMD(J)=ACLOD(J)
      THETA(J)=BRNG(J)+HDG(J)
      IF(THETA(J).GT.6.283186) THETA(J)=THETA(J)-6.283186
      THETAD(J)=BRNGD(J)+HDGD(J)
      IF(THETAD(J).GT.360.0) THETAD(J)=THETAD(J)-360.0
  5   CONTINUE
 51   FORMAT(7F11.5)
 52   FORMAT(6F13.5)
 53   FORMAT('1',36X,'LISTING OF EMITTER TARGET DATA AND ',
     1'AIRCRAFT NAVIGATION DATA',///,13X,'TARGET PARAMETERS'
     2,37X,'AIRCRAFT PARAMETERS',//,' TYPE      TIME',4X,
     3'FREQ     BRNG    PRF   PW  MO / TIME     HDG      ALT',
```

```
     46X.'LAT       LONG       N.VEL      E.VEL      ROLL       PITCH'
     5.2X,'MO'.//)
54    FORMAT(' TGT',I3,1X,F9.3,1X,F6.1,1X,F7.5,1X,F6.1,1X,
     1F4.2,1X,I1)
55    FORMAT(' NAV',43X,F9.3,1X,F7.5,1X,F7.1,1X,F8.5,1X,F8.5
     11X,F8.3,1X,F8.3,1X,F8.5,1X,F8.5,1X,F3.0,/)
56    FORMAT(5F13.5)
      RETURN
      END
```

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3. ABSTRACT

A scheme to locate emitter positions using post flight processing of discrete airborne emitter bearing angles-of-arrival information and recorded aircraft position coordinates by Kalman filter techniques is developed. The signal intercept system was assumed to be operating in a multi-emitter environment and all data was sampled at discrete but time varying intervals. The aircraft position data is filtered directly in latitude and longitude and emitter locatoins are computed in latitude and longitude using vector methods. An extended Kalman filtering scheme is developed to compute emitter coordinates directly in latitude and longitude coordinates.

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